INSTITUTION

OF

MECHANICAL ENGINEERS.

28060

PROCEEDINGS.

1872.

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1872.

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Assistant Secretary.—Alfred Bache,
Institution of Mechanical Engineers,
81 Newhall Street, Birmingham.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1872.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1871. Adamson, Joseph, Messrs. Daniel Adamson and Co.'s Works, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Kenilworth Villa, South Cliff, Scarborough.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Locomotive Superintendent, Moscow and Razan Railway Moscow, Russia.
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works. Ilkeston Road, Nottingham.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., 40 Elm Avenue, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1856. Anderson, John, LL.D., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.

1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.

1858. Armstrong, Sir William George, C.B., D.C.L., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1857. Ashbury, James Lloyd, 66 Grosvenor Street, London, W.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.

1865. Bailey, John, Messrs. Courtney Stephens and Co., Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.

1872. Bailly, Philimond, 49 Rue du Pont Neuf, Brussels.

1866. Baines, William, London Works, Soho, near Birmingham.

1866. Baker, Samuel, 22 Oil Street, Liverpool.

1865. Baldwin, Martin, Bovereux Iron Works, Bilston.

1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, care of Hugh Barclay, Westfield, Surbiton, Kingston-on-Thames.

1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.

1866. Barnard, Clement, 4 Billiter Square, London, E.C.

1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.

1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 18 Duke Street, Westminster, S.W.

1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.

1860. Batho, William Fothergill, Melrose House, Erdington, Birmingham.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham.

1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.

1869. Beattie, William George, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington. (*Life Member.*)

1864. Beckton, James George, Whitby, Yorkshire.

1865. Bell, Charles, Sunfield House, Old Dover Road, Blackheath, London, S.E.

1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne; and The Hall, Washington, County Durham.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, 13 Broad Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1865. Benson, George Henry, Messrs. Freeman Benson and Co., 9 Rumford Street, Liverpool.

1867. Berkley, George, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1866. Birkbeck, John Addison, 8 Acklam Terrace, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1865. Bladen, Charles, Blochairn Iron Works, Glasgow.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington.

1869. Bloomer, Benjamin Giles, Pelsall Coal and Iron Works, near Walsall.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1872. Boistel, Georges, 11 Rue de Châteaudun, Paris.

1872. Bolton, Major Frank, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1869. Borrie, John, Billingham, near Stockton-on-Tees.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.
1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)
1869. Boyd, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.
1854. Bragge, William, Sir John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.
1868. Breeden, Joseph, 156 Cheapside, Birmingham.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.
1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)
1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
1865. Brown, George, Rotherham Iron Works, Rotherham.
1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.
1847. Brown, James, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1869. Browne, Walter Raleigh, Docks Engineer's Office, Underfall Yard, Cumberland Road, Bristol.
1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta, India.
1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.
1872. Brunner, Henry, Messrs. John Hutchinson and Co.'s Alkali Works, Widnes, near Warrington.
1865. Bryant, Frederick William, Albert Bridge Works, 33 Cheyne Walk, Chelsea, London, S.W.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 23 Lower King Street, Manchester.
1872. Bullock, Thomas, Jun., Messrs. Thomas Bullock and Sons, Button Manufacturers, Cliveland Street Works, Birmingham.
1870. Burgh, Nicholas Proctor, 78 Waterloo Bridge Road, London, S.E.
1858. Burn, Henry, Atlas Iron Works, Litchurch, Derby.
1871. Burrows, James, Wigan.
1870. Bury, William, 5 New London Street, London, E.C.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.
1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1867. Campbell, Daniel, 20 Budge Row, Cannon Street, London, E.C.
1864. Campbell, David, 105 Eglinton Street, Glasgow.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1869. Carpmael, Frederick, Westhill House, near Leeds.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1872. Carr, Thomas, Richmond Road, Montpelier, Bristol.
1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.
1864. Carrington, William Thomas, St. Antholius' Chambers, 26 Budge Row, Cannon Street, London, E.C.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1870. Carver, James, Messrs. Carver and Mosley, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.
1869. Caspersen, Hans William, Engineer, Danish Government Railway Service ; 27 Ashfield Terrace West, Newcastle-on-Tyne.
1869. Chadwick, John, Prince's Bridge Iron Works, Water Street, Salford, Manchester.
1871. Chamberlain, Walter, Messrs. Nettlefold's Screw Works, Smethwick, near Birmingham.
1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.
1872. Chatwin, Thomas, Victoria Works, Berkley Street, Birmingham.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

1866.. Claridge, Thomas, Messrs. Claridge North and Co., Phœnix Foundry, near Bilston.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood, near Newton-le-Willows.

1859. Clark, George, Monkwearmouth Engine Works, Sunderland.

1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.

1862. Clark, James, Wellington Foundry, Leeds.

1869. Clark, Thomas, Elswick Marine Engine Works, Newcastle-on-Tyne.

1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.

1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1869. Clerk, Francis North, Mitre Galvanising Works, Bilston Road, Wolverhampton.

1866. Cleworth, Charles, District Locomotive Superintendent, East Indian Railway, Jumalpore, India.

1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.

1847. Clift, John Edward, Redditch Gas Works, Redditch.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.

1854. Cochrane, John, 3 Hyde Park Gate, London, S.W.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

1847. Coke, Richard George, Mining Engineer, Chesterfield.

1867. Coke, William Langton, 11 Great Queen Street, Westminster, S.W.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1868. Coulson, William, Mining Engineer, Shamrock House, Durham.

1864. Cowans, John, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.

1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
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1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.
1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.
1864. Crowe, Edward, Messrs. Hopkins Gilkes and Co.'s Works, Tees Engine Works, Middlesbrough.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1869. Daglish, John, Mining Engineer. Tynemouth, near North Shields.
1866. Daniel, Edward Freer, Cherry Orchard, Shrewsbury.
1866. Daniel, William, 37 Camp Road, Leeds.
1872. Danson, Thomas James, Messrs. Thomas Murray and Co.'s Engine Works, Chester-le-Street, near Fence Houses.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1868. Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.
1863. Davy, Alfred, Alliance Chambers, George Street, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1861. Dawson, Benjamin, 9 St. George's Square, Sunderland.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, 10 Strand, London, W.C.; and Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
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1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1872. Dobson, Benjamin Alfred, Kay Street Machine Works, Bolton.
1868. Dodman, Alfred, St. James's Works, Lynn.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.

1857. Douglas, George K., Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.
1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1860. Dyson, George, Saltburn-by-the-Sea, Yorkshire.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1859. Eassie, Peter Boyd, Messrs. William Eassie and Co., Railway Saw Mills, Gloucester.
1858. Easton, Edward, Messrs. Easton Amos and Sons, Grove Works, Southwark Street, London, S.E.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1870. Elsdon, Robert, Brockham Green, near Reigate.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1857. Evans, John Campbell, 28 Grosvenor Road, Highbury New Park, London, N.
1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.
1869. Eyth, Max, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 30 John Street, Bedford Row, London, W.C.
1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds.
1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
1857. Fairlie, Robert Francis, Palace Chambers, Victoria Street, Westminster, S.W.
1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.
1865. Faviell, Samuel Clough, Messrs. Taylor Brothers and Co.'s Works, Clarence Iron Works, Leeds.
1872. Fearn, John Wilmot, Mining Engineer, Knifesmith Gate, Chesterfield.
1870. Ferguson, Henry Tanner, District Locomotive Superintendent, South Devon, Cornwall, and West Cornwall Railways, Carn Brea Works, Redruth.
1854. Fernie, John, Ventnor, Isle of Wight.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Platt Lane Colliery, Wigan.
1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 30 Springfield Mount, Leeds.
1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Taff Vale Railway, Cardiff Docks, Cardiff.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1871. Forrest, William John, Assistant Engineer, Intercolonial Railway, Ottawa, Canada.

1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1868. Forster, John, Messrs. Westray and Forster, Abbey Road, Barrow-in-Furness, Lancashire.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.
1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1866. Fox, Charles Douglas, 6 Delahay Street, Westminster, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1870. Freeman, George Frederick, Broughton Copper Works, Broughton Road, Manchester.
1852. Froude, William, F.R.S., Chelston Cross, Torquay.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Langford House, Soho Hill, Birmingham.
1870. Garstang, James H., Bank Top Foundry, Blackburn.
1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.
1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.
1848. Gibbons, Benjamin, The Leasowes, near Birmingham.
1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.
1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.
1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.
1869. Gillies, Malcolm, Great Eastern Railway, Locomotive Department, Stratford, London, E.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Högbo, Sweden.
1871. Gowenlock, Alfred Hargreaves, care of Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta, India.
1869. Grainger, James Nixon, Public Works Department, Chepauk, Madras, India.
1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, St. Katherine's Dock House, London, E.
1870. Gray, Matthew, 100 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, 2 Great George Street, Westminster, S.W.
1861. Green, Edward, Jun., Phœnix Works, Wakefield.
1871. Greener, John Henry, 84 Lombard Street, London, E.C.
1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1860. Grice, Frederic Groom, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.
1871. Grover, Captain George Edward, R.E., International Exhibition, South Kensington, London, W.
1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.
1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.
1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)
1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, Landore Steel Works, Swansea.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1863. Hall, Joseph, Graz Iron Works, Graz, Styria, Austria.
1871. Hall, William Silver, Engineer, Babbington Collieries, Cinder Hill, Nottingham.
1871. Halpin, Druitt, 24 Great George Street, Westminster, S.W.
1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.
1869. Hambling, Thomas Crump, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1870. Hannah, Joseph Edward, Consett Water Works, Waskerley, Darlington.
1870. Harding, George Edward, 52 Broadway, New York, United States.
1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1871. Harrison, Joseph Edward, Messrs. Cochrane and Co.'s Works, Woodside Iron Works, near Dudley.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William Arthur, Cambridge Street Works, Manchester.

1872. Hartnell, Wilson, Messrs. E. R. and F. Turner's Works, St. Peter's Iron Works, Ipswich.

1871. Hartness, John, Lloyds' Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1872. Hassall, Henry Thomas, Messrs. Hassall and Singleton, Phœnix Foundry, Freeman Street, Birmingham.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1848. Hawthorn, William, 92 Pilgrim Street, Newcastle-on-Tyne.

1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.

1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, Bank Chambers, Cook Street, Liverpool.

1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.

1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1864. Hetherington, William Isaac, 84 King William Street, London Bridge, London, E.C.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Hill Top, Sharples, near Bolton.

1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.

1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.

1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.

1871. Hill, Alfred C., Middlesbrough.

1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.

1869. Hind, Henry, Central Works, Queen's Road, Nottingham.
1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.
1866. Hodgson, Charles, 21 Gresham Street, Old Jewry, London, E.C.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1871. Holiday, Joseph, Union Foundry, Bradford, Yorkshire.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Messrs. Hawthorn's Engine Works, Newcastle-on-Tyne.
1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, 3 Southwell Gardens, Gloucester Road, South Kensington, London, S.W.
1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1867. Hopper, William, Machine Works, Moscow, Russia: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)
1868. Horsley, Thomas, Kirkby Old Hall, Pinxton, Alfreton.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.
1851. Horton, Joshua, Island House, Handsworth, Birmingham.
1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Houghton, John Campbell Arthur, Messrs. Cochrane and Co.'s Works, Woodside Iron Works, near Dudley.
1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.
1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Brook Steel Works, Brookhill, Sheffield.
1866. Hoyle, William Jennings, Elswick Works, Newcastle-on-Tyne.
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Messrs. Daniel Adamson and Co.'s Works, Newton Moor Iron Works, Hyde, near Manchester.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, 116 Nottingham Street, Sheffield.

1872. Hunter, John Law, Borough Engineer, Wigan.

1864. Hutchinson, Edward, Messrs. Pease Hutchinson and Co., Skerne Iron Works, Darlington.

1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta, India: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s Works, Soho Iron Works, Bolton.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.

1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1872. Jackson, William Francis, Atlas Steel and Iron Works, Sheffield.

1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1858. Jaffrey, George William, The Firs, Partick Hill, Glasgow.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1868. James, John, Sunny Bank, Pontypool.

1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.

1861. Jessop, Thomas, Park and Brightside Steel Works, Sheffield.

1854. Jobson, John, Derwent Foundry, Derby.

1868. Jobson, Robert, Phœnix Works, Dudley.
1863. Johnson, Bryan, Messrs. Johnson and Ellington, Flookersbrook Foundry, Chester.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.
1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.
1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.
1872. Jones, William Richard Sumption, Deputy Superintendent, Government Foundry and Workshops, Roorkee, India.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1869. Keep, Alfred, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1867. Kellett, John, 27 King Street, Wigan.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.
1866. Kershaw, John, 24 Duke Street, Westminster, S.W.
1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1870. Kinsey, Henry, Robin Hood Engine Works, Queen's Road, Nottingham.
1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1866. Lambert, William Blake, 6 Vanbrugh Park, Blackheath, London, S.E.
1863. Lancaster, John, M.P., Bilton Grange, Rugby.
1870. Lancaster, Joshua, Mostyn Coal and Iron Works, Holywell, North Wales.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1857. Laybourne, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourne, Richard, Rhymney Iron Works, Tredegar.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, Iron Ore Office, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Town Hall Buildings, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1870. Leonard, Edward James, East India Chambers, 23 Leadenhall Street, London, E.C.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Leslie, Bradford, 8 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons' Works, Tyne Iron Works, Blaydon-on-Tyne, County Durham.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Wolverhampton.
1860. Lewis, Thomas William, Abercanaid House, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., Engineer, Silksworth Colliery, near Sunderland.
1866. Little, George, Messrs. Platt Brothers and Co.'s Works, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, care of Edward J. Lloyd, 6 Victoria Grove, Fulham Road, London, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Old Park Iron Works, Wednesbury.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1866. Lloyd, Joseph Foster, 1 Temple Row West, Birmingham.

1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury; and Wassell Grove, near Stourbridge.

1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1862. Lloyd, Wilson, Darlaston Green Iron and Steel Works, near Wednesbury.

1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.

1869. Lockhart, Humphrey Campbell, Birmingham Plate Glass Works, Smethwick, near Birmingham.

1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.

1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.

1866. Lord, Edward, Canal Street Works, Todmorden.

1861. Low, George, St. Peter's Iron Works, Ipswich.

1872. Lukin, Augustus Stephen, Borough Engineer, Carmarthen.

1854. Lynde, James Gascoigne, Town Hall, Manchester.

1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1872. Lyster, George Fosbery, Engineer-in-Chief, Mersey Dock Estate, Liverpool.

1869. Mabbutt, Thomas, Abingdon Gun Works, Shadwell Street, Birmingham.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.

1856. Mackay, John, Mount Hermon, Drogheda.

1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.

1865. MacNay, William, Shildon Engine Works, Darlington.

1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.

1867. Mallet, Robert, F.R.S., 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Manning, John, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.

1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1857. March, George, Union Foundry, Dewsbury Road, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1871. Marsh, Henry William, Islip Iron Works, near Thrapston.

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Marshall, James, South Skelton Mines, Marske-by-the-Sea, Yorkshire.
1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.
1859. Marshall, William Ebenezer, 1 Beech Grove Terrace, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.
1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.
1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.
1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., Deputy Controller, Dover.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1857. Masselin, Armand, 14 Rue de Lancry, Paris.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1847. Matthews, William Anthony, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1853. Maudslay, Henry, care of John Maxwell, Rochford House, Beulah Hill, Upper Norwood, London, S.E. (*Life Member.*)
1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1869. May, George, Mining Engineer, North Hetton and Pittington Collieries, Fence Houses.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, Calicut, Madras, India.
1847. McClean, John Robinson, M.P., F.R.S., 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Wordsley Foundry, Stourbridge.
1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.

1868. McKay, Benjamin, Small Arms Factory, Small Heath, near Birmingham.
1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, 28 Fawcett Street, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, care of Messrs. Elkington and Co., Newhall Street, Birmingham.
1867. Merryweather, Richard M., Fire Engine Works, 63 Long Acre, London, W.C.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, Curzon Chambers, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1870. Moberley, Charles Henry, Messrs. Eastons and Anderson's Works, Erith Iron Works, Erith, London, S.E.
1872. Moon, Richard, Jun., Mersey Steel and Iron Works, Caryl Street, Liverpool.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1872. Moorsom, Warren Maude, London and North Western Railway, Crewe.
1864. Morgan, Joshua Llewelyn, Llanelly Iron and Tinplate Works, near Abergavenny.
1867. Morgans, Thomas, Newarne, Lydney.
1868. Morris, William, Waldridge Colliery, Chester-le-Street, near Fence Houses.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1872. Mulliner, Charles, Whalley Range, Manchester.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.

1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)

1861. Naylor, John William, Wellington Foundry, Leeds.

1858. Naylor, William, 57 Mildmay Park, Islington, London, N.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.

1869. Nelson, James, Bonners Field Foundry, Sunderland.

1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.

1866. Newdigate, Albert Lewis, 14 Dover Street, Piccadilly, London, W. (*Life Member.*)

1862. Newton, William Edward, 66 Chancery Lane, London, W.C.

1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.

1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.

1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.

1870. Nye, Henry, Messrs. Varrall Elwell and Middleton's Works, 9 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s Works, Fairfield Engine Works, Govan, Glasgow.

1866. Oliver, William, Victoria Foundry, Chesterfield.

1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.

1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1870. Osborn, Samuel, Clyde Steel Works, Sheffield.

1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo: St. James' Hotel, 77 Piccadilly, London, W.

1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.

1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.

1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley, Lancashire.

1868. Parker, Frederick, Greenfield Road, Harborne, Birmingham.

1868. Parker, Henry, Locomotive Superintendent, Mexican Railway, Puebla, Mexico: (or care of Frederick Parker, 117 Unett Street, Birmingham.)

1869. Parker, Thomas, Mersey Wheel Works, Stourbridge.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1866. Parton, Thomas, Mining Engineer, New Road, Willenhall, near Wolverhampton.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works Gorton Foundry, Manchester.

1869. Peacock, Ralph, Cyclops Iron Works, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.

1848. Pearson, John, 7 Old Hall Street, Liverpool.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, Messrs. Bunnett and Co., 90 Queen Street, London, E.C. ; and New Cross Works, Deptford, London, S.E.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1860. Peyton, Edward, Bordesley Works, Birmingham.

1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.

1867. Pidgeon, Daniel, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1859. Platt, John, M.P., Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1870. Platt, William Wilkinson, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1869. Player, John, Clydach Foundry, near Swansea.

1866. Plum, Thomas Edward Day, Messrs. Sharp Stewart and Co.'s Works, Atlas Works, Manchester.

1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.

1872. Pole, William, F.R.S., 3 Storey's Gate, Westminster, S.W.

1860. Ponsonby, Edward Vincent, 2 Mountjoy Park, Clonliffe Road, Dublin.

1866. Porter, Charles Talbot, Allen Engine Works, Fourth Avenue, Harlem, New York, United States.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 5 Pemberton Square, Boston, Massachusetts, United States.
1870. Powell, Thomas, Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1869. Purves, John, Superintending Engineer, Liverpool New York and Philadelphia Steam Ship Co., Water Street, Liverpool.
1866. Putnam, William, Darlington Forge, Darlington.

1870. Radcliffe, William, Messrs. Hampton Radcliffe and Co., Phœnix Direct Steel Works, Ickles, near Rotherham.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1864. Ramage, Robert, 95 Miles Street, Liverpool.
1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness, Lancashire.
1872. Rankine, William John Macquorn, LL.D., F.R.S., 59 St. Vincent Street, Glasgow.
1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.
1867. Ratliffe, George, Lancashire Steel Works, Gorton, Manchester.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1872. Rawlins, John, Metropolitan Carriage and Wagon Works, Saltley Works, Birmingham.
1870. Reed, Edward James, C.B., 8 Victoria Chambers, Victoria Street, Westminster, S.W.
1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.
1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.
1865. Richardson, John, Methley Park, near Leeds.
1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1872. Rofe, Henry, Jun., Resident Engineer, Corporation Water Works, Rochdale.
1868. Rogers, William, Imperial Railway Department, Osaka, Japan.
1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1853 Ronayne, Joseph P., Rinn Ronain, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, 15 George Street, Mansion House, London, E.C. (*Life Member.*)
1847. Russell, John Scott, F.R.S., 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, Avonside Engine Works, St. Philip's, Bristol.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1872. Salmon, Frank Barton, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service; 19 Great George Street, Westminster, S.W.
1871. Sanders, Richard David, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Bombay, India: (or care of George Sanders, Bank of England, London, E.C.)
1861. Sanderson, George Grant, 2 Kenwood Road, Sharrow, near Sheffield.
1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1869. Schanschieff, Alexandre, 6 Great Winchester Street Buildings, London, E.C.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, 34 St. Ann's Street, Cross Street, Manchester.
1868. Scott, George Lamb, Crown Iron Works, Heywood Street, Clowes Street, West Gorton, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James H. Murray, 16 Brunswick Street, Barnsbury Road, London, N.)
1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.
1864. Seddon, John, 98 Wallgate, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta, India; and 4 The Grove, Balham, Surrey, S.W.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool.
1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.
1872. Shoolbred, James Nelson, 3 York Buildings, Dale Street, Liverpool.
1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, D.C.L., F.R.S., 3 Great George Street, Westminster, S.W.
1871. Simon, Henry, 7 St. Peter's Square, Manchester.
1847. Sinclair, Robert, 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, St. Philip's, Bristol.
1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.
1866. Smith, Edward Fisher, The Priory Offices, Dudley.
1866. Smith, Fereday, Bridgewater Offices, Manchester.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Strand, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1871. Soames, Peter, 10 Southampton Street, Strand, London, W.C.
1859. Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Blackladies, Brewood, near Stafford.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.
1869. Stenson, Foster, Burton Iron Works, Burton-on-Trent.
1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.
1866. Stephens, John Classon, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, Punjab Club, Lahore, India: (or care of Charles P. B. Shelley, 113 Victoria Street, Westminster, S.W.)
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., District Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1861. Sumner, William, 2 Brazenose Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Messrs. Eastwood Swingler and Co., Victoria Foundry, Litchurch, near Derby.
1872. Symington, William Weldon, Colne Valley Iron Works, Halstead.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.
1864. Thomas, Thomas, Bronygarn Villa, Roath, Cardiff.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.
1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.
1870. Thomson, William Sparks, 6A Victoria Street, Westminster, S.W.
1868. Thornewill, Robert, Burton Iron Works, Burton-on-Trent.
1861. Thwaites, Robinson, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.
1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.
1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.
1867. Turner, Henry, Canada Works, Birkenhead.
1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.
1867. Tweddell, Ralph Hart, 14 Roker Terrace, Roker, near Sunderland.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, 11 Great Queen Street, Westminster, S.W.
1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

1868. Vallance, Frederick Bevoley, Alicel Engine Works, Bridge Street, Greenwich, S.E.
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1865. Wainwright, William, West Central Wagon Works, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.
1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Boundary Street North, Liverpool.
1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.
1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.
1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Burton Iron Works, Burton-on-Trent.
1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.
1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.
1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.
1872. Welch, Edward John Cowling, Messrs. Francis Morton and Co.'s Galvanised Iron Works, Naylor Street, Liverpool.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1871. West, Henry Joseph, Messrs. Siebe and West, Mason Street, Lambeth, London, S.E.
1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.
1867. Weston, Thomas Aldridge, care of William T. Watts, 81 Parade, Birmingham.

1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1872. Whieldon, William, Messrs. Whieldon Lecky and Co., Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain; (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.

1867. Wilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.

1867. Wilkes, John, Tube Works, Bordesley Mills, Birmingham.

1868. Wilkieson, Colonel Charles Vaughan, R.E., care of Messrs Richardson and Co., 13 Pall Mall, London, S.W.

1865. Williams, Edward, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.

1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.

1870. Willman, Charles, 3 Cleveland Terrace, Middlesbrough.

1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1865. Wilson, James Edwards, Brunswick House, Bromley, Kent.

1863. Wilson, John Charles, 17 Gracechurch Street, London, E.C.

1857. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.

1860. Wilson, William, 37 Great George Street, Westminster, S.W.

1865. Winby, Clifford Etches, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.

1867. Winby, Frederick Charles, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.

1862. Winby, William Edward, Rabone Bridge Iron Works, Smethwick, near Birmingham.

1872. Winn, Charles William, 30 Easy Row, Birmingham.

1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.

1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham.

1871. Withy, Edward, Messrs. Withy and Alexander, Middleton Iron Shipbuilding Yard, Hartlepool.

1868. Wood, Lindsay, Mining Engineer, Hetton Colliery, Hetton, near Fence Houses.

1869. Wood, Thomas James Vickers, Springfield Mill, Cleckheaton, near Normanton.

1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.

1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.

1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.

1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.

1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.

1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.

1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.

1871. Wright, William, District Engineer, Cornwall Railway, Lostwithiel.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin.
1847. Fairbairn, Sir William, Bart., LL.D., F.R.S., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1868. Beale, Montague, 1 Great Winchester Street Buildings, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's,
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, 32 Priory Street, Dudley.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1872. Hewlett, William Henry, Iron Merchant, Wigan.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1858. Lawton, Benjamin C., 48 Westgate Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, Crown Buildings, Queen Victoria Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1868. Matthews, Thomas Bright, Phœnix Steel Works, Sheffield.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester.
1856. Pettifor, Joseph, Midland Railway, Derby.
1867. Roe, Thomas, Jun., Siddals Road, Derby.
1859. Sherriff, Alexander Clunes, M.P., Perdiswell Hall, Worcester.
1863. Storey, Thomas R., Deptford Brass Works, Sunderland.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Farnley Iron Works, Leeds.
1865. Warden, Thomas, Lionel Street, Birmingham.

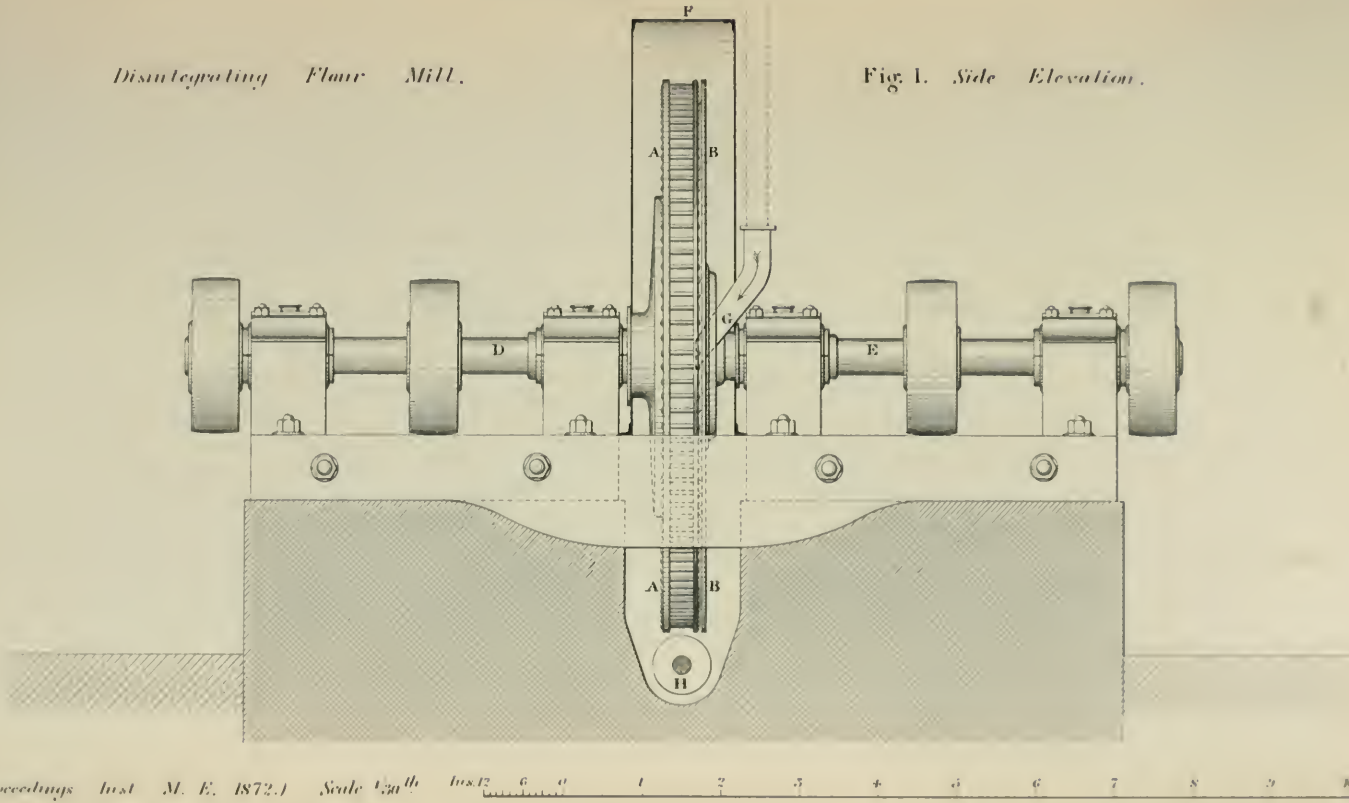
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)
1867. Watts, William Thomas, 81 Parade, Birmingham.
1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.
1870. Wright, Edwin Arthur, 22 Snow Hill, Wolverhampton.

GRADUATES.

1872. Armstrong, Thomas, Phœnix Steel Works, Sheffield.
1872. Bagshawe, Walter, Airedale Foundry, Leeds.
1869. Bainbridge, Emerson, Nunnery Colliery Offices, Sheffield.
1869. Blake, Frederick William, Birmingham Heath Boiler Works, Spring Hill, Birmingham.
1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.
1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street Birmingham.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Works, Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Westhoughton, near Bolton.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.
1872. Napier, Robert Twentyman, Messrs. Denny and Co.'s Engine Works, Dumbarton.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1871. Thurgood, Ernest Charles, Saffron Walden.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1872. Wilson, Alfred, 90 Marton Road, Middlesbrough.
1867. Wright, John Roper, Messrs. Charles Cammell and Co.'s Works, Grimesthorpe Steel Works, Sheffield.

DISINTEGRATING MACHINE. *Plate 1.*

Disintegrating Flour Mill. Fig. 1. *Side Elevation.*



(Proceedings Inst. M. E. 1872.) *Scale 1/30th*

DISINTEGRATING MACHINE.

Plate 2.

Disintegrating Flour Mill.

Fig. 2.
Transverse
Section.

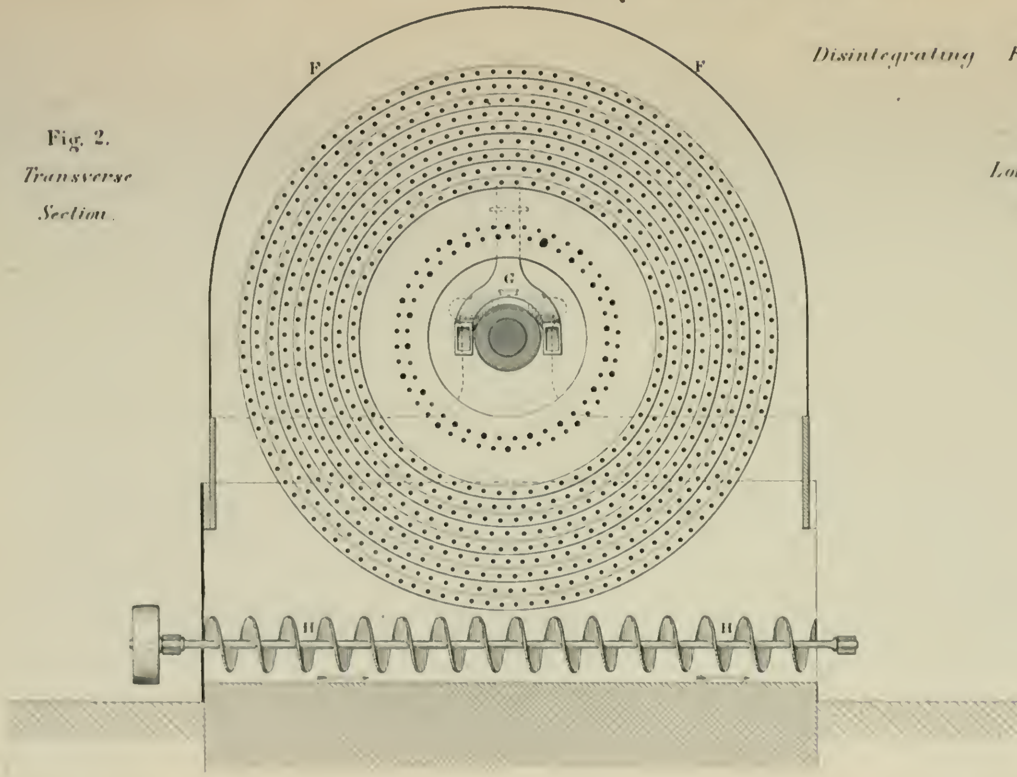
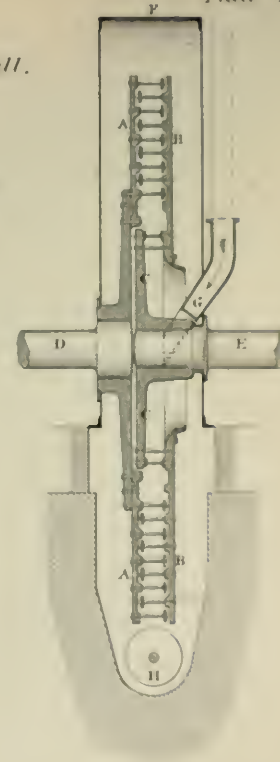


Fig. 3.
Longitudinal
Section.



(Proceedings Inst. M. E. 1872.)

Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet

DISINTEGRATING MACHINE.

Fig. 4. *Transverse Section of Disintegrating Flour Mill, showing contrary rotation of alternate cages of beaters.*

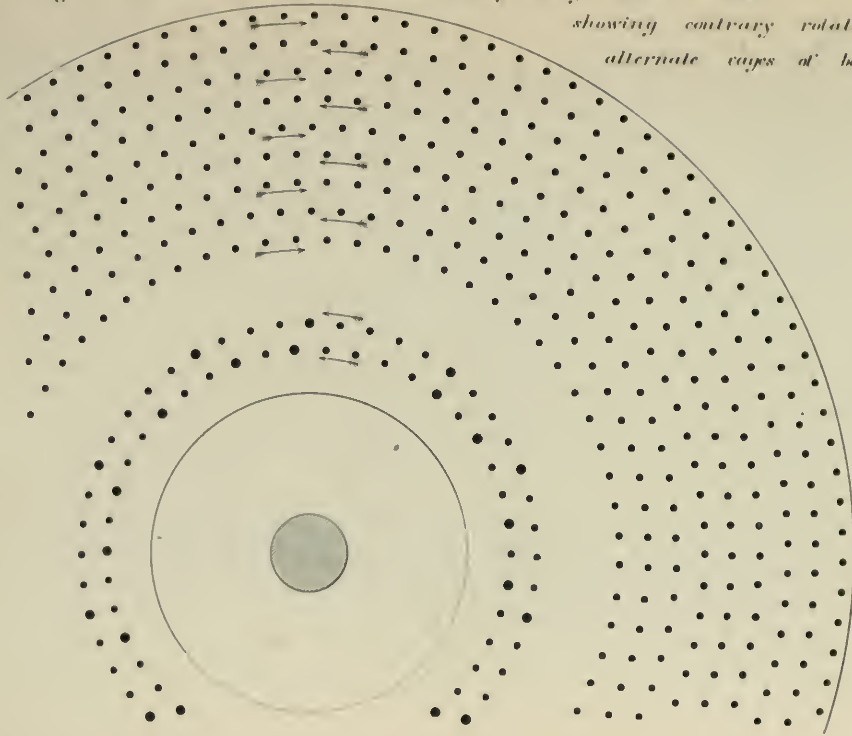


Fig. 5.

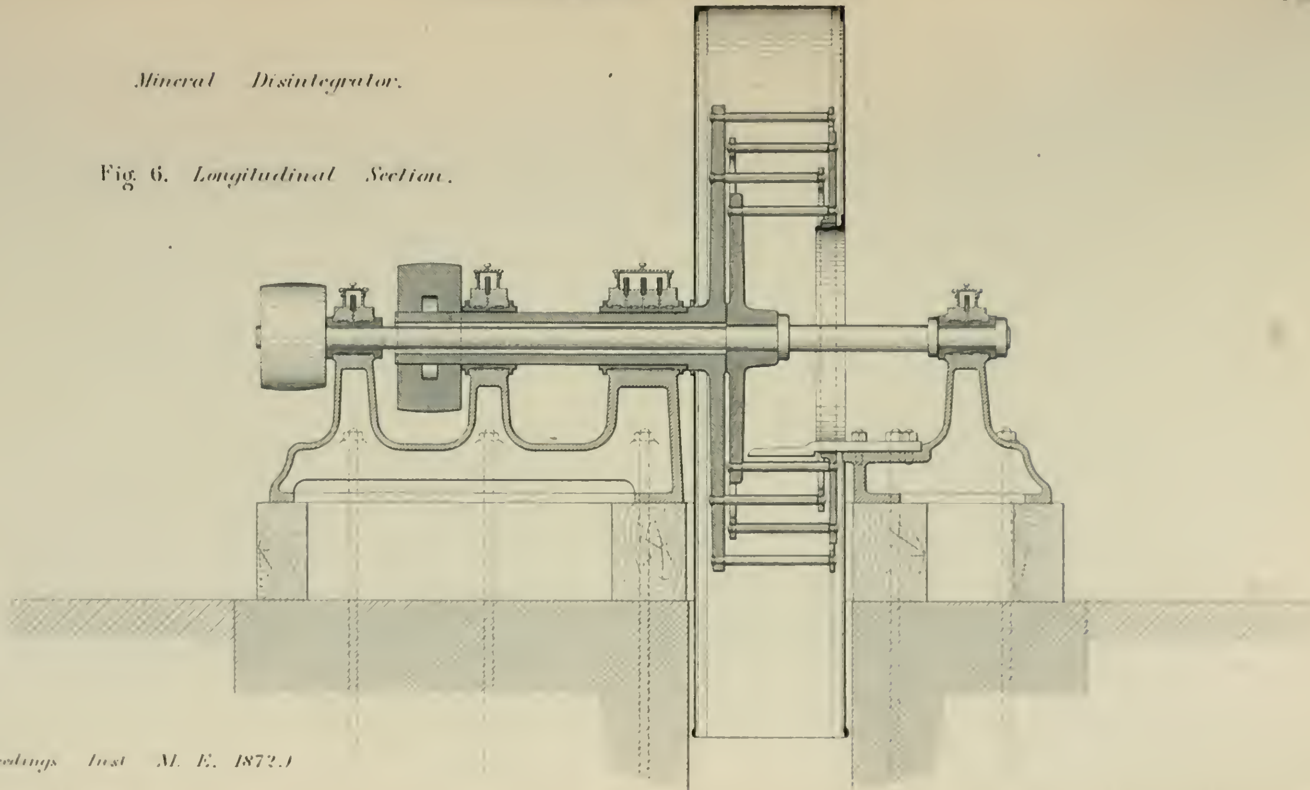
Scale 1/15th

DISINTEGRATING MACHINE.

Plate 4.

Mineral Disintegrator.

Fig. 6. *Longitudinal Section.*



(Proceedings Inst. M. E. 1872.)

Scale 1/24th

DISINTEGRATING MACHINE.

Mineral Disintegrator.

Fig. 7. *End Elevation.*

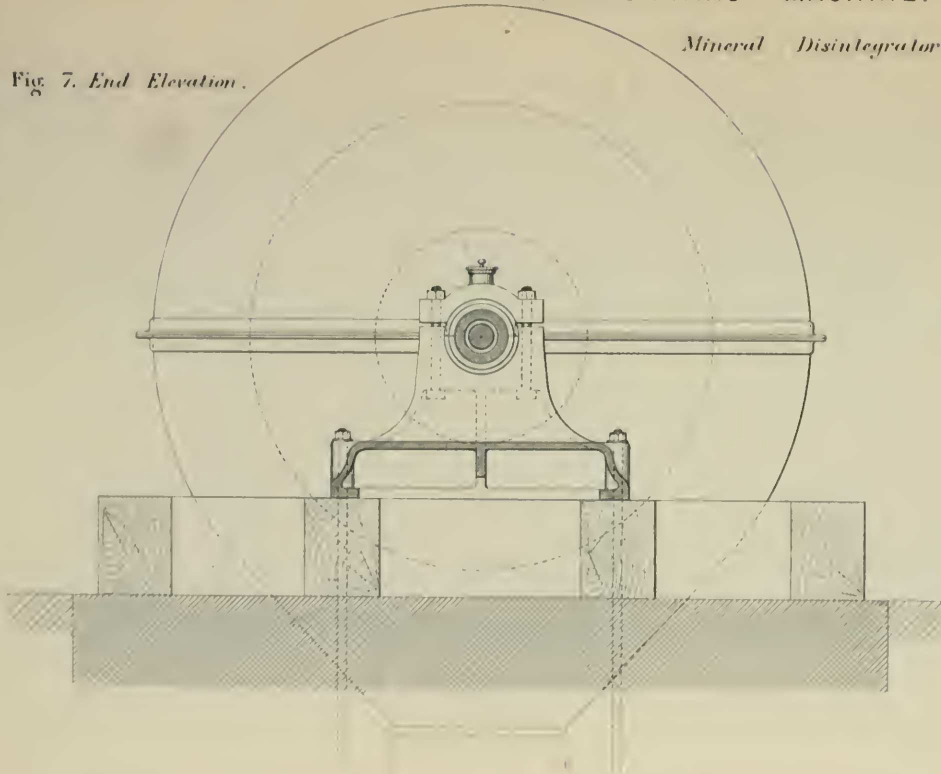
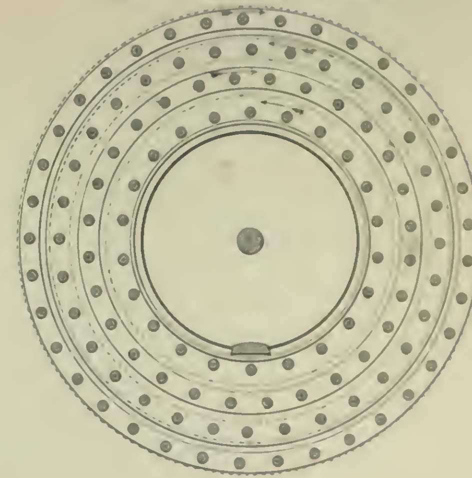


Fig. 8. *Transverse Section.*



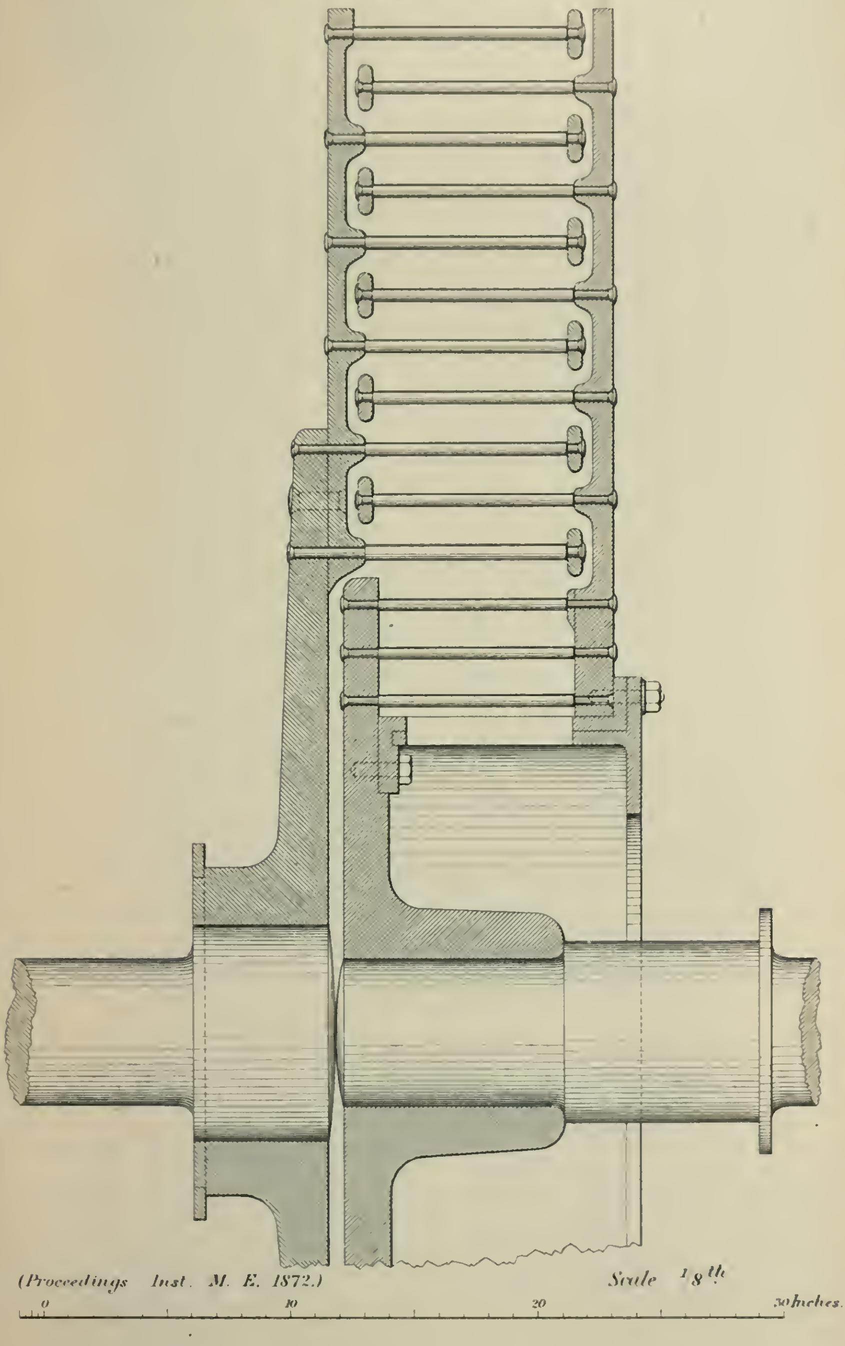
Scale $1/24$th

Ins. 12 6 0 1 2 3 4 5 6 Feet

(Proceedings Inst. M. E. 1872.)

DISINTEGRATING MACHINE. *Plate 6.*

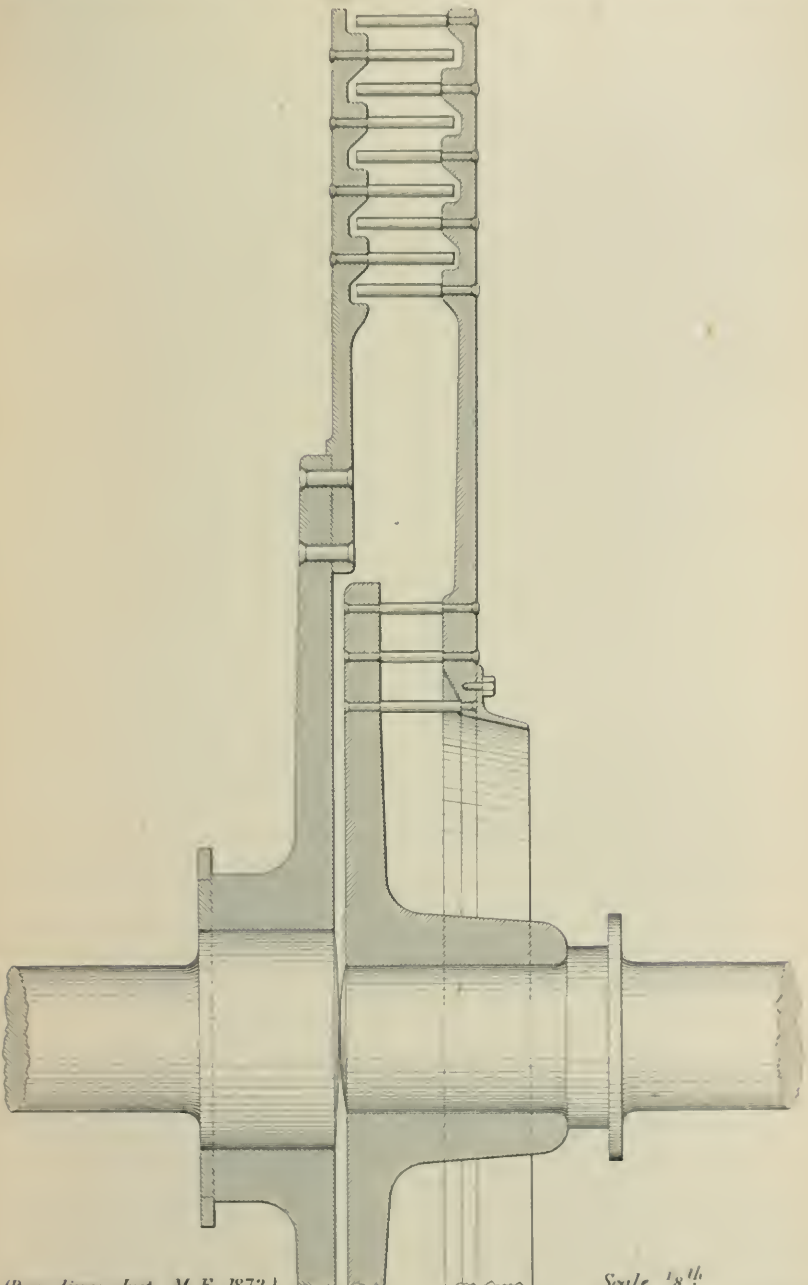
Fig. 9. Longitudinal Section of Disintegrating Flour Mill at present in use.



(Proceedings Inst. M. E. 1872.)

Scale 1/8th.

Fig. 10. *Longitudinal Section of improved Disintegrating Flour Mill*



(Proceedings Inst. M. E. 1872.) *Scale 1/8th*

0 10 20 30 Inches.

RIVETED JOINTS.

Different modes of Fracture of Riveted Joints.

Fig. 1. *Shearing Rivet.*

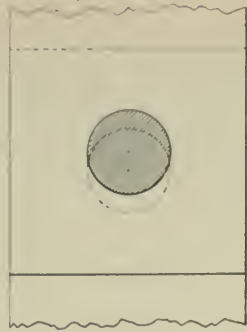


Fig. 2. *Crippling.*

Fig. 3. *Tearing out.*

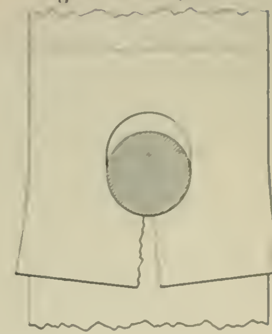


Fig. 6.

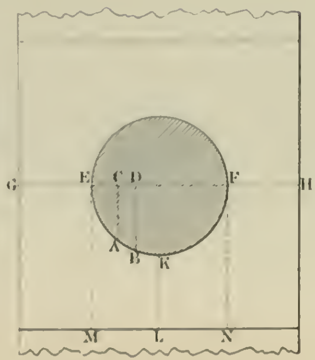


Fig. 5. *Shearing Plate.*

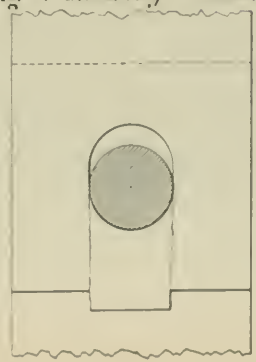
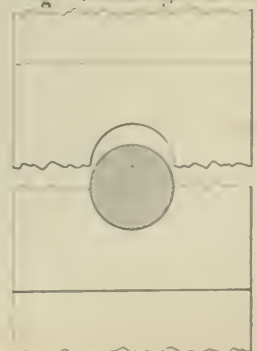


Fig. 4. *Tearing across*



Scale 1/2

(Proceedings Inst. M. E. 1872.)

RIVETED JOINTS.

Plate 9.

Fig. 7.

Fig. 8. *Single Riveting.*

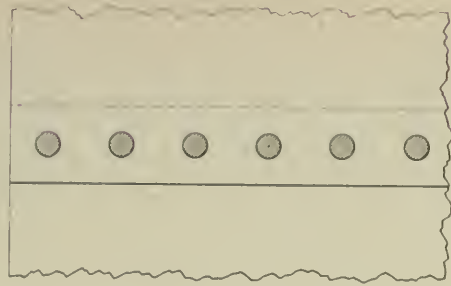


Fig. 12. *Chain Riveting.*

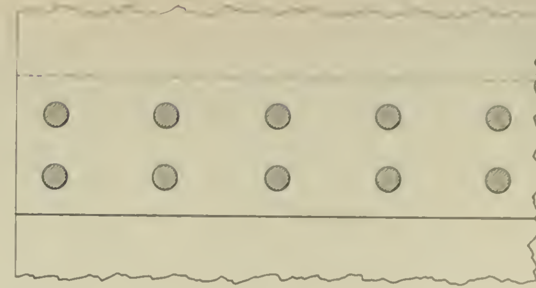


Fig. 13.

Zigzag Riveting.

Fig. 9. *Ratio 40 per cent.*

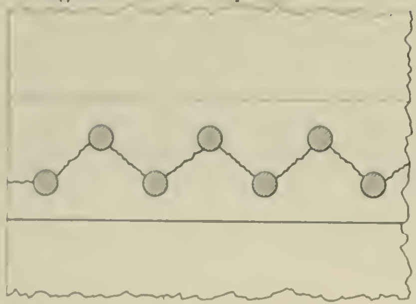


Fig. 10. *Ratio 62 per cent.*

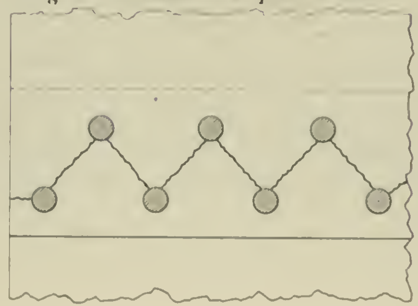
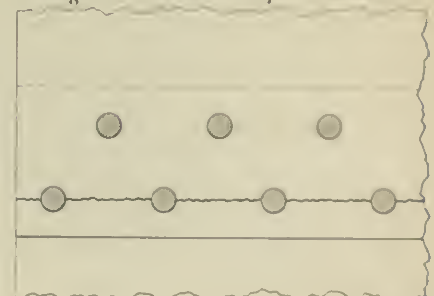


Fig. 11. *Ratio 67 per cent*



(Proceedings Inst. M. E. 1872.)

Scale 1/8th.

RIVETED JOINTS.

Single - Riveted Butt - Joints.

Fig. 14.

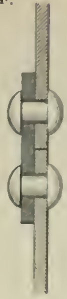


Fig. 15. *Single Cover.*

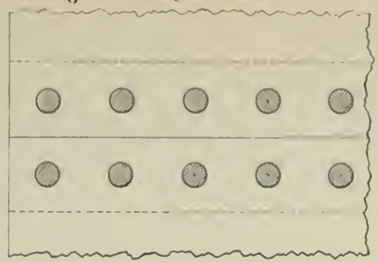


Fig. 16. *Double Cover.*

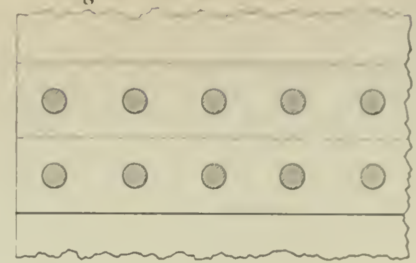
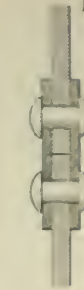


Fig. 17.



Double - Riveted Butt - Joints.

Fig. 18.

Fig. 19. *Double Cover, Chain Riveting.*

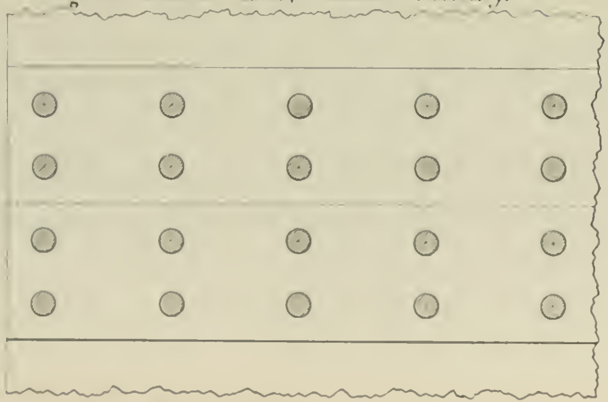


Fig. 20. *Double Cover. Zigzag Riveting.*

(Proceedings Inst. M. E. 1872.)

Scale

RIVETED JOINTS.

Fig. 21. *Diagonal - Joint Boiler.*

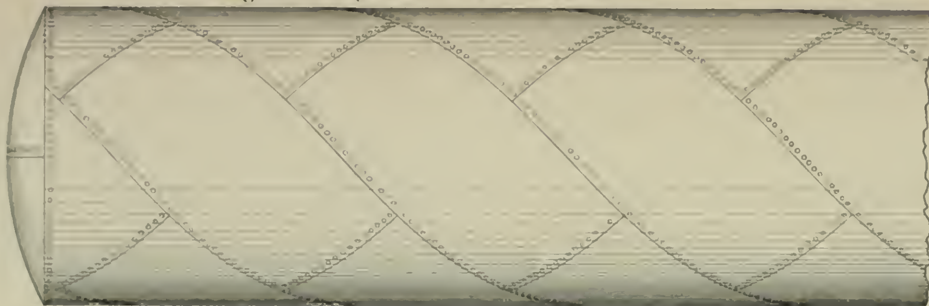
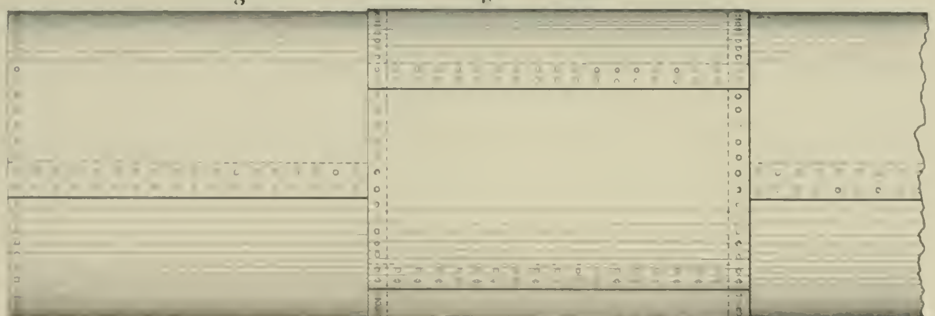


Fig. 22. *Thickened - Edge Plates.*



Scale 1/48th

Fig. 23. *Section of Thickened - Edge Plates.*

Scale 1/3rd

(Proceedings Inst. M. E. 1872.)

PROCEEDINGS.

25 January, 1872.

The Twenty-fifth Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 25th January, 1872; the Chair was taken by John Ramsbottom, Esq., the retiring President, who was succeeded by the President elect, Charles William Siemens, Esq.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1872.

The Council on this occasion of the Twenty-fifth Anniversary present to the Members the annual statement of the position of the Institution and the progress during the past year.

The Financial statement of the affairs of the Institution for the year is satisfactory, showing that the balance on 31st December 1871 was £7227 18*s.* 8*d.*, after payment of the accounts due to that date. Of this amount the sum of £5973 16*s.* 2*d.* is invested in London and North Western Railway 4 per cent. Debenture Stock, registered in the names of Mr. John Ramsbottom, Mr. Frederick J. Bramwell, and Mr. Sampson Lloyd, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for last year 1871, and report that the following Abstract of Receipts and Expenditure rendered by the Treasurer is correct. (*See Abstract appended.*)

The total number of Members of all classes in the Institution for last year is 875, of whom 4 are Honorary Life Members, 31 are Associates, and 21 are Graduates; 58 of the whole are resident in various foreign countries.

The following deceases of Members of the Institution have occurred during the past year 1871:—

Joseph Hamilton Beattie, ...	London.
Fleetwood James Cannell, ...	Sheffield.
Samuel Thomas Cooper, ...	Leeds.
Joseph Freeman, ...	London.
Thomas Frost, ...	Sheffield.
John Harding.	Leeds.
John Hosking, ...	Gateshead.
Ferdinand Kohn.	London.
William Mathews.	Great Malvern.
Peter Dale Nichol, ...	Sunderland.
George Piggott.	Birmingham.
Alfred Stansfield Rake.	Newcastle-on-Tyne.
Samuel Taylor, ...	Leeds.
Thomas Wicksteed.	Leeds.
William Wray, ...	Burton Stather.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and with this view Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Reports of the United States Commissioners to the Paris Exhibition of 1867; from the Commissioners.

Report of Inspection of European Mints, by James M. Napier; from the author.

On the Manufacture of Guns, by M. S. Jordan; from the author.

Engineering and Engineers, by Lieut-Col. B. H. Martindale, C. B., R. E.; from the author.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Collection of Engineering Drawings; from the École des Ponts et Chaussées, Paris.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Proceedings of the Royal Artillery Institution; from the Institution.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Transactions of the Institution of Surveyors; from the Institution.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Professional Papers of the Corps of Royal Engineers; from the Royal Engineer Establishment.

Lectures on the Construction of Wrought-iron Bridges, by W. Cawthorne Unwin; from the Royal Engineer Establishment.

Manual of Instruction in Photography, by Lieut. Abney, R.E.; from the School of Military Engineering.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Journal of the Hannover Architect and Engineer's Society; from the Society.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Report of the Smithsonian Institution for 1869; from the Institution.

Geological Survey of Indiana, report for 1869; from Professor E. T. Cox, State Geologist.

Report of the Director of the Cincinnati Observatory; from the Director, Mr. Cleveland Abbe.

Congressional Directory of the United States Congress 1871; from the Clerk of the Printing Records, Mr. Ben Perley Poore.

Finance Report of the United States Treasury for 1870; from the Smithsonian Institution.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.

Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
United States Patent Office Report for 1868; from the Commissioner.
Journal of the Society of Arts; from the Society.
Beeton's Dictionary of Information in Science, Art, and Literature; from the Editor.
The Engineer; from the Editor.
Engineering; from the Editor.
The Mechanics' Magazine; from the Editor.
The Artizan Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.

The Papers brought before the meetings during the past year, and the discussions that took place upon them, have possessed much practical interest, and form a valuable addition to the Proceedings of the Institution. The Council request the aid and co-operation of the Members in carrying out the objects of the Institution and maintaining its advanced position, by contributing Papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

On the Mechanical Ventilation of the Liverpool Passenger Tunnel on the London and North Western Railway; by the President.
Description of a Balanced Slide-Valve for Locomotive Engines; by Mr. William G. Beattie.
On Whittle's plan for preventing Deposit and Incrustation in Steam Boilers; by Mr. George Addenbrooke.
On Ashton and Storey's Steam-Power Meter and Continuous Indicator; by Mr. John H. Storey.
On the principal constructions of Breech-Loading Mechanism for Small Arms, and their relative mechanical advantages; by Mr. William P. Marshall.
On the Manufacture of Hæmatite Iron; by Mr. William Crossley.
On the Preliminary Treatment of the Materials used in the Manufacture of Pig Iron in the Cleveland district; by Mr. I. Lowthian Bell.

Description of the improved Compound-Cylinder Blowing Engines at the Lackenby Iron Works, Middlesbrough; by Mr. Alfred C. Hill.

On the general Geological Features of the Cleveland Iron District; by Mr. John Jones.

Description of the Break Drums and the mode of working at the Ingleby Incline on the Rosedale Branch of the North Eastern Railway; by Mr. John A. Haswell.

On a Simple construction of Steam Engine Governor, having a close approximation to perfect action; by Mr. Jeremiah Head.

On Steam Boilers with Small Water-space, and Root's Tube Boiler; by Mr. Charles Cochrane.

Description of Miller's Cast-iron Steam Boiler; by Mr. John Laybourne.

On Steam Pressure Gauges; by Mr. Ernest Spon.

The Annual Meeting of the Institution last summer was held in Middlesbrough, and the Council have particular pleasure in expressing their special thanks to the Cleveland Institution of Engineers, and the Honorary Local Secretaries, Mr. Jeremiah Head and Mr. Gilbert Gilkes, for the very excellent arrangements and the cordial and handsome reception given to the Members on the occasion; and also their thanks to the proprietors of the works that were so liberally thrown open for the inspection of the Members; and to the railway authorities for the special arrangements granted for the excursions. The Council desire especially to acknowledge the value of the opportunity afforded to the Members for visiting the numerous Blast-Furnaces, Rolling Mills, and Engineering and Shipbuilding Works in Middlesbrough and the neighbourhood, and the Ironstone Mines of the Cleveland District. They refer with great satisfaction to the advantages arising from these Annual Meetings of the Institution in different localities, in consequence of the facilities thereby afforded for the personal communication of the Members in different districts, and the opportunities of visiting important Engineering Works on those occasions; and this feature in the arrangements has been specially marked in the present instance.

The Council have given careful consideration to a suggestion made by several members at the Middlesbrough meeting, that one of the three meetings now held annually in Birmingham should be

held in London. This subject the Council consider to be one having so many bearings, and to be of so much importance, that they have not felt themselves justified in coming as yet to any final conclusion; but they will not cease to give it their serious attention, until it is ripe for decision.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot taken at the present Meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air-pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

Blast Engines, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks – distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars

of performance and cost of work done—steam road rollers, particulars and results.

Hot-Air Engines—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—stone-dressing machinery.

Sugar Mills, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

Weaving Machinery, for manufacture of different materials—improvements in looms, &c.

Knitting Machinery, worked by hand or by power—particulars of improvements.

Rope-Making Machinery—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines—strength and proportions of riveted joints.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

Pressure Gauges, for steam and water—varieties of construction—durability and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of testing.

Girders of Cast and Wrought Iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction

of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam power to steering.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manu-

facture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces. best construction—consumption of fuel, and heat obtained.

Cupolas, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

Converting Furnaces, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Blowing Fans, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals—self-acting locking apparatus.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam and hydraulic breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

Abstract of Receipts and Expenditure.

For the year ending 31*st December*, 1871.

Cr.		£	*s.*	*d.*
By Balance 31st Dec. 1870 ; Invested	4500 0 0			
In Bank	1809 12 11	6309	12	11
,, Subscriptions from 71 Members in arrear . .		213	0	0
,, do. from 3 Associates in arrear		9	0	0
,, do. from 2 Graduates in arrear		4	0	0
,, do. from 696 Members for 1871		2088	0	0
,, do. from 25 Associates for 1871		75	0	0
,, do. from 19 Graduates for 1871		38	0	0
,, do. from 11 Members in advance for 1872 . .		33	0	0
,, Entrance Fees from 43 New Members		86	0	0
,, do. from 1 New Associate		2	0	0
,, do. from 1 New Graduate		1	0	0
,, do. from 2 Graduates transferred to Members.		2	0	0
,, Sale of Extra Reports		14	3	6
,, Interest ; From Bank	20 17 9			
On £4500 invested at 4 per cent., from 15 July 70 to 5 Aug. 71 .	189 12 5			
On £1496 6 2 invested at 4 per cent., half year to 15 July 71 .	30 0 0	240	10	2
		£9115	6	7

Dr.		£	*s.*	*d.*
To Printing and Engraving Reports of Proceedings	510 14 11			
Less Authors' copies of Papers, repaid	28 18 0	481	16	11
,, Stationery, Binding, Printing of Circulars, &c. .		92	16	3
,, Office Expenses, Clerks, and Petty Disbursements		108	18	8
,, Coals, Gas, and Water		25	5	11
,, Expenses of Meetings		55	18	5
,, Fittings and Repairs			18	11
,, Travelling Expenses		47	15	2
,, Parcels		3	11	5
,, Postages		85	6	9
,, Salaries		863	0	0
,, Insurance		2	10	0
,, Rent and Taxes		119	9	6
Balance 31st Dec. 1871 ; Invested	5973 16 2			
In Bank	1254 2 6	7227	18	8
		£9115	6	7

(Signed) SAMPSON LLOYD,
CHARLES COCHRANE,
WALTER MAY, } Finance Committee.

25th January, 1872.

MEMOIRS

OF MEMBERS DECEASED IN 1871.

Joseph Hamilton Beattie was born on 12th May 1808, and was first engaged professionally in 1835 under Mr. Joseph Locke as an assistant engineer on the Grand Junction Railway. In 1837 he superintended under Mr. Locke the construction of a large portion of the buildings, workshops, and permanent way of the London and Southampton Railway; and upon the completion of this line he undertook the charge of the carriage and wagon stock and the maintenance of the station buildings. In 1840 he introduced several improvements in the construction of railway rolling stock, consisting of improved forms of buffing apparatus, breaks, couplings, wooden railway wheels, an apparatus for placing an increased proportion of the weight of a locomotive engine upon the driving wheels when necessary, and a duplex lathe for turning up the tyres of wheels. In addition to the carriage and wagon department of the London and South Western Railway, the locomotive department was also placed under his charge in 1851, when he brought out improvements in the construction of permanent way, modes of attaching tyres by dovetailed clips, apparatus for heating the feed water of locomotive engines, and fireboxes for burning coal and coke together in locomotives; and upon the two latter subjects he communicated a paper to the Institution (see Proceedings Inst. M. E. 1854 page 24). He subsequently brought out further improvements in the fireboxes and other parts of locomotive engines, and also an oil axlebox for engines and carriages, and safety guide-rails to be used on sharp curves and bridges; several of his inventions have been extensively used on various railways. In 1863 he designed and carried out the arrangement of new workshops and machinery for the locomotive and carriage departments of the London and South Western Railway at Nine Elms, London. His

death took place on 18th October 1871 in his sixty-fourth year, after an illness of about three weeks' duration. He became a Member of the Institution in 1848.

Fleetwood James Cannell was born at Garston near Liverpool on 8th September 1820, and served his apprenticeship as an engineer at Haigh Foundry, Wigan. He was for several years employed on the London & South Western and Great Eastern Railways under Mr. J. V. Gooch. In 1853 he was engaged for a short time as manager of Messrs. Harvey and Co.'s works, Hayle, and in the same year he removed to Wednesbury to take the management of the Old Park Engineering Works belonging to Messrs. Lloyds Fosters and Co., where he remained till the latter part of 1868. He then became manager of Sir John Brown and Co.'s works, Sheffield, but on account of failing health he resigned this position shortly before his death, which took place on 14th March 1871 in the fifty-first year of his age. He became a Member of the Institution in 1860.

Samuel Thomas Cooper was born in June 1831 at Worsbrough Hall near Barnsley, his father being the principal partner in the firm of Messrs. Cooper Field and Hood, the founders of the Leeds Iron Works, Leeds. He commenced his business career at an early age in connection with these works, of which he subsequently became the principal partner. After having taken an active part in the management for nearly twenty years, he went in 1865 to reside at Bulwell Hall near Nottingham, still retaining his interest in the firm. His death occurred suddenly from an attack of apoplexy on 10th February 1871 in the fortieth year of his age. He was also a partner in the Worsbrough Cold-Blast Iron Works, and in the Silkstone and Worsbrough Collieries near Barnsley; and was a magistrate for the county of Nottingham. He became a Member of the Institution in 1853.

Joseph Freeman was born in London on 6th November 1819, and was for some years with his father in the business of a stone

merchant, but eventually became connected with the iron trade. About 1850 he became the representative in London of the Low Moor Iron Works, and continued to occupy that position till his death, which occurred on 26th February 1871 in the fifty-second year of his age. He became a Member of the Institution in 1856.

John Harding was born at Killingworth near Newcastle-on-Tyne on 8th May 1812; and in 1827 was engaged under Mr. George Stephenson on the works of the Liverpool and Manchester Railway, on the completion of which he was appointed by Mr. Stephenson as resident engineer of the Whitby and Pickering Railway, and afterwards to the Sheffield and Rotherham Railway, and thence to the Leeds end of the Midland Railway. He was subsequently engaged as contractor upon several large works, and ultimately became a partner in the Beeston Manor Iron and Coal Works near Leeds, and continued so to the time of his death, which took place on 7th September 1871 at the age of fifty-nine. He became a Member of the Institution in 1858.

John Hosking was born on 8th May 1808 at Gwythian, a small village near Hayle, Cornwall, his father being a farm-labourer, and on leaving the village school he was sent to work in the fields; but having a strong love of books and a great desire for knowledge, he prevailed upon his parents to let him attend a better school at Copperhouse, near Hayle. At about the age of thirteen he himself began to teach in his native village, teaching the children during the day, and having a class for adults in the evening. When about sixteen years of age he was engaged by Mr. Gray, engineer of Wheal Prosper Mine, as general assistant and draughtsman at the mine, to keep up the underground plan of the workings; but this mine being stopped very shortly afterwards, he then became engaged by Mr. Arthur Woolf, with whom he continued during the working of Wheal Alfred Mine, where Mr. Woolf erected the largest of his double-cylinder engines, of which an elaborate set of drawings was made by Mr. Hosking. In 1828 he went for a short time to Messrs. Sandys Vivian and Carne, at the Copperhouse Foundry,

near Hayle; after which he obtained employment in the works of Messrs. Braithwaite and Ericsson in London, and was with them when they competed for the prize in the locomotive trial on the Liverpool and Manchester Railway in 1829. After remaining there four or five years, during which he acquired a very high reputation as a mechanical draughtsman, he occupied for some time the position of engineer at the Park Gate Iron Works near Rotherham, but ultimately returned to London, and was employed by Mr. Thomas Wicksteed in getting out the designs for the Cornish pumping engines for the different waterworks in London of which Mr. Wicksteed was the engineer. He was then appointed by Mr. Robert Stephenson to carry out for him and superintend the erection of the High Level Bridge at Newcastle-on-Tyne; and in order to select the most suitable mixture of cast iron for the ribs of this bridge, he carried out for Mr. Stephenson an elaborate series of experiments upon the strength of cast iron, which were published in the Commissioners' Report upon Railway Structures; numerous experiments upon the transverse strength of tubes of different sectional shapes were also made by him about the same time for Mr. Stephenson, and were published in Mr. Edwin Clark's work upon the Britannia and Conway Tubular Bridges. Upon the completion of the High Level Bridge in 1850, he became the engineer to Messrs. Hawks Crawshay and Sons of Gateshead, who had been the contractors for the ironwork of the bridge; and with them he remained till his death, a period of more than twenty-one years. Amongst the numerous works of great magnitude executed by the firm during that time may be mentioned the renovation in 1858 of the remarkable cast-iron arch over the river Wear at Sunderland, under Mr. Robert Stephenson. Mr. Hosking was the inventor of an improved construction of valve for pumping engines, composed of a nest of india-rubber rings or balls, and he read a paper upon this subject at the meeting of the Institution held in Newcastle in 1858 (see Proceedings Inst. M. E. 1858 page 249); these valves are in regular use at several of the metropolitan waterworks, as well as in the provinces, and have proved completely successful. He also invented the wooden pavement adopted for the lower roadway of

the High Level Bridge and also for the Sunderland Bridge and elsewhere, consisting of wooden blocks placed on end, with the separating interstices filled up with pitch and hard stone broken small. After an illness of less than a week, Mr. Hosking's death took place at Gateshead on 23rd December 1871 at the age of sixty-three. He became a Member of the Institution in 1858.

Ferdinand Kohn was born on 23rd May 1837 in Neu Schloss, Bohemia, where his father was a manufacturer of textile fabrics. After studying at the Academies and Polytechnic Institute in Vienna, he spent about a year and a half in the locomotive shops of the South Austrian Railways, and in 1859 settled in London in connection with the late Mr. Andrew Shanks, with whom he remained for some years. In 1862 he was appointed to report to the Austrian Government upon the machinery exhibited in the London International Exhibition of that year. In 1865 he became actively engaged in introducing the Bessemer process upon the Continent, especially in Austria, and was thus led to make a special study of the iron and steel manufacture. He also devoted much attention to the manufacture of sugar from beetroot, in connection with which he was instrumental in promoting the success of M. Robert's diffusion process. After the Paris Exhibition of 1867 he was for a long time occupied in the design and erection of works in Austria and France for carrying out the Siemens-Martin process. In connection with professional literature he was the author of many articles upon the metallurgy of iron and steel, and upon beet sugar manufacture; and also published in 1869 a work upon the iron and steel manufacture. His death took place in London on 2nd May 1871 in the thirty-fourth year of his age. He became a Member of the Institution in 1869.

William Mathews was born on 17th October 1796 at Hagley, Worcestershire; and having entered the office of Mr. Matthias Attwood, who founded the Corngreaves Steel Works near Halesowen, he subsequently became a partner with Mr. Finch in the Waterloo Furnaces, Westbromwich. In 1833 he took the Corbyn's Hall Furnaces and Colliery, Kingswinford, which he retained to the end

of his life. He acquired a minute knowledge of all the practical details and the successive improvements in the manufacture of pig iron from the South Staffordshire ores, as well as a very extensive acquaintance with everything relating to the iron and coal trades of that district; and was constantly consulted upon all matters affecting these interests. He took an active part in the promotion of various railways in the district, especially the Oxford Worcester and Wolverhampton Railway, of which as well as of the South Wales Railway he was a director. His death took place in Birmingham on 2nd September 1871, shortly after a sudden attack of paralysis, in the seventy-fifth year of his age. He became a Member of the Institution in 1853, and in 1860 contributed a paper on the Ten Yard Coal of South Staffordshire and the mode of working (see Proceedings Inst. M. E. 1860 page 91).

PETER DALE NICHOL was born on 16th September 1831 at Newcastle-on-Tyne, and after serving an apprenticeship at the works of Messrs. Robert Stephenson and Co. he was engaged in 1853 as one of the locomotive engineers on the East Indian Railway, and was stationed at Allahabad during the time of the mutiny. After visiting England in 1858 he returned at the end of that year to India, where he remained until 1867, being for some years locomotive superintendent on the East Indian Railway at Allahabad. Shortly after his return to England in 1867 he became the managing director of the North Eastern Marine Engineering Works at Sunderland. He lost his life on 17th January 1871, at the age of thirty-nine, in consequence of injuries received from the bursting of a steam pipe on board the steamship "Canton" at Sunderland. He became a Member of the Institution in 1858.

GEORGE PIGGOTT was born at Birmingham on 27th May 1833, and in 1849 entered his father's gasholder and boiler works at Spring Hill. After passing through the workshops and drawing office, and particularly studying the details of the business, he became a partner in the firm in 1859, and then devoted much of his

time to designing machinery specially adapted for his work. Amongst the improvements he introduced may be mentioned a revolving facing machine for facing the ends of bars of all sections; a hydraulic apparatus for punching, shearing, and riveting gasholder and other plates; and an oiling apparatus. He also invented a rotary gas-exhauster, and an improved water-lute for telescopic gasholders which has been extensively adopted; also a self-acting apparatus for locking together the inner and outer lifts of gasholders when lowering. He had been engaged for a considerable time in designing an electric telegraph instrument on a new principle, when he was seized with an illness which proved fatal on 19th September 1871 in the thirty-ninth year of his age. He became a Member of the Institution in 1856.

Alfred Stansfield Rake was born on 2nd January 1831 at Shaftesbury, Dorsetshire, and commenced his professional course in the works of Messrs. Gilkes Wilson and Co. at Middlesbrough. Having a decided preference for iron shipbuilding he was engaged for some time with the firm of Messrs. Coutts and Parkinson at Willington Quay near Newcastle-on-Tyne, and afterwards entered into partnership as an iron shipbuilder at Middlesbrough; but the business proving less successful than was anticipated, he retired from it, and subsequently occupied responsible situations successively with Messrs. Dodds and Son at Rotherham, Messrs. Stephenson and Co. at Newcastle-on-Tyne, and Messrs. Fairbairn and Co. at Manchester, after which he was for two years with Messrs. Brown and Craig, Victoria Dockyard, near Cork. On leaving Ireland he established himself in 1867 as a consulting engineer and naval architect in Newcastle-on-Tyne, where he soon obtained a large and advantageous connection. His death took place on 23rd January 1871 at the age of forty, his health having failed some time previously. He was elected a Member of the Institution in 1862.

Samuel Taylor was born on 5th August 1822 at Low Moor, and in 1834 began to obtain a knowledge of the manufacture of best Yorkshire iron by working at the Low Moor Iron Works;

he afterwards entered the service of Messrs. Hood and Cooper at the Leeds Iron Works, where his elder brother James was manager. In 1857 he joined his brothers James and George in establishing the Clarence Iron Works, Leeds, for the manufacture of best Yorkshire iron. He died on 16th December 1871 at the age of forty-nine, having been a Member of the Institution from 1868.

Thomas Wicksteed was born at Shrewsbury on 26th January 1806, and after residing some years with Mr. Arthur Aikin at the Society of Arts, London, was articled to Mr. Alexander Galloway. On the termination of his pupilage he became an assistant of Mr. Henry R. Palmer, the Engineer to the London Docks, with whom he remained until 1829, during the construction of extensive additions to the docks and warehouses. Being then appointed Engineer to the East London Water Works, he managed these works with such economy and success, that although costly additions had to be made to the reservoirs and pumping engines, yet the company became increasingly prosperous. Important economy in working was due to his introduction of the Cornish pumping engine in place of the less economical engines previously used. His attention was first directed to this form of engine in 1835, and after visiting the Cornish mines, conducting experiments, and publishing the results obtained, he succeeded in inducing the waterworks company in 1837 to transplant an engine from Cornwall to their pumping station at Old Ford, London. So incredible at first appeared the extent of economy attending the working of this engine, that he conducted a set of most careful experiments extending over upwards of a year, in order to establish the correctness of his views; and in 1841 he published these experiments with his conclusions derived from them. A second and much larger engine upon the same principle was shortly afterwards erected by him at Old Ford. Between 1838 and 1845, while still resident engineer to the East London Water Works, Mr. Wicksteed became the consulting engineer to the Grand Junction, Vauxhall, Southwark, and Kent Water Works, and carried out extensive additions to these several works. During the same

period he constructed new waterworks at Hull and Wolverhampton, and made considerable additions to the waterworks at Brighton, and subsequently to those at Scarborough. He also reported upon the waterworks of Leeds, Liverpool, Lichfield, Leamington, Cork, Kingston in Jamaica, Valparaiso, Boston in the United States, and other places. In 1841 he was consulted upon the waterworks and sewerage of Berlin, and also about the same period in reference to the barrage of the Nile. Having been led to investigate the subject of the sewerage of towns and the disposal of the sewage, he began in 1845 to experiment upon the use of lime for disinfecting sewage, and in 1847 became engineer to the London Sewage Company, which was formed for the purpose of purifying the sewage of London and manufacturing manure from it by his process. The plans were prepared for an intercepting sewer along the north bank of the Thames to a pumping station and reservoir at Barking Creek; but the scheme required more capital than could then be raised, and the project was subsequently abandoned. To Mr. Wicksteed however is due the origination of the idea of constructing an intercepting sewer parallel to the Thames, at a depth below all the existing sewers, and of creating an adequate fall to the intercepting sewer by pumping at its outlet. He had previously proposed the same plan for Berlin in 1841, and subsequently both proposed and executed the design at Leicester. So much time and attention did he devote to this subject, that he neglected to some extent his reputation as a waterworks engineer, and eventually gave up all his connection with the different London waterworks, resigning his position as engineer to the East London Water Works in 1851. Works for the manufacture of manure from sewage having been established under his advice at Leicester were carried on for some years with success, so far as the purification of the sewage was concerned, the river Soar being restored by this means to nearly its original purity; but without the same good fortune in the production of saleable manure. Large quantities of manure were produced, but the quality was not strong enough to compete with other manures already used by farmers; so that eventually the works became a commercial failure, and were handed over to the corporation of Leicester, by whom however they

continue to be used for purifying the sewage. At Leicester Mr. Wicksteed carried out a complete system of drainage; and he was also consulted respecting the sewerage of Leamington, Maidstone, and Scarborough. His health having suffered from the unfavourable commercial result of the sewage works at Leicester, he was gradually retiring from professional practice, when in 1865 he was affected by an illness which never afterwards left him. This led him to give up work altogether, and caused his death on 15th November 1871, in the sixty-sixth year of his age. He became a Member of the Institution in 1863.

William Wray was born in 1830 at Burton Stather in Lincolnshire, and was brought up to the shipbuilding business of his father, Mr. John Wray, at that place; and in 1857 he assumed the management of the business. Having acquired a good knowledge of the principles of shipbuilding, he introduced improvements in the lines of the numerous brigs, schooners, fishing smacks, and other vessels built by his firm. He died on 5th June 1871 at the age of forty-one. He became a Member of the Institution in 1866.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed.

The CHAIRMAN announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year :—

PRESIDENT.

CHARLES WILLIAM SIEMENS, . .	London.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, . . .	Newcastle-on-Tyne.
FREDERICK J. BRAMWELL, . . .	London.
CHARLES COCHRANE, . . .	Dudley.
THOMAS HAWKSLEY, ...	London.
SAMPSON LLOYD, ...	Wednesbury.
WILLIAM MENELAUS, ...	Merthyr Tydvil.

COUNCIL.

CHARLES EDWARDS AMOS. . .	London.
GEORGE HARRISON, . . .	Birkenhead.
JOHN HICK, M.P., ...	Bolton.
FREDERICK W. KITSON, . . .	Leeds.
WALTER MAY, . .	Birmingham.
JOHN NAPIER, ...	Glasgow.
JOHN ROBINSON, ...	Manchester.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, C.B., .	Newcastle-on-Tyne.
SIR WILLIAM FAIRBAIRN, BART., .	Manchester.
JAMES KENNEDY, ...	Liverpool.
ROBERT NAPIER, . . .	Glasgow.
JOHN PENN, ...	London.
JOHN RAMSBOTTOM, . . .	Manchester.
SIR JOSEPH WHITWORTH, BART., .	Manchester.

COUNCIL.

Members of Council remaining in office.

John Anderson, ...	Woolwich.
Henry Bessemer, ...	London.
William Clay, ...	Birkenhead.
Edgar Gilkes, ...	Middlesbrough.
Thomas Greenwood, . . .	Leeds.
Charles P. Stewart, . . .	Manchester.
Francis W. Webb, . . .	Crewe.
Percy G. B. Westmacott, . .	Newcastle-on-Tyne.

TREASURER.

Henry Edmunds, ...	Birmingham.

SECRETARY.

William P. Marshall, . . .	Birmingham.

ASSISTANT SECRETARY.

Alfred Bache, ...	Birmingham.

The following New Members were also elected :—

MEMBERS.

Thomas Richard Bayliss, . .	Birmingham.
Georges Boistel, ...	Paris.
Thomas Carr, ...	Bristol.
John Wilmot Fearn, . . .	Chesterfield.
Richard Amelius Lewis, . . .	Blaydon-on-Tyne.
John McConnochie, . . .	Cardiff.
Thomas Parker, ...	Manchester.
John Rawlins, ...	Birmingham.

ASSOCIATE.

William Henry Hewlett, . .	Wigan.

GRADUATES.

Walter Bagshawe, . . .	Manchester.
Alfred Slater, ...	Gloucester.

The PRESIDENT elect, Mr. Siemens, in taking the Chair, alluded to the many eminent men who had preceded him in the office of President of the Institution, from the time of their first President, Mr. George Stephenson, to that of his own immediate predecessor, Mr. Ramsbottom; and he desired to thank the Members for the honour they had now conferred upon himself in electing him to that post, and to assure them that he was fully sensible of the responsibilities attaching to the position. With regard to the term of office of their late President, it was particularly gratifying to notice how the Institution had prospered and advanced under his presidency; the number of members had been increasing, and the papers read at the meetings had been of a most interesting and important character. At the annual meeting held last summer at Middlesbrough, papers of great value and importance had been contributed, and the Institution had been received there by the local members and their friends in the most cordial manner. He had great pleasure in announcing that a similar cordial invitation had been received from Liverpool for the annual meeting of the present year; and he hoped the Members generally would make a point of attending on that occasion.

The following paper, communicated through Mr. Edward Easton, of London, was then read:—

DESCRIPTION OF THE DISINTEGRATING FLOUR MILL, AND MACHINE FOR PULVERISING MINERALS &c., WITHOUT GRINDING, CRUSHING, OR STAMPING.

By Mr. THOMAS CARR, of Bristol.

The object of the writer in designing this machine was to obtain the means of pulverising unfibrous materials of different kinds, without subjecting them to friction or compression, one or both of which objections appertain more or less to all other methods hitherto used for the reduction of materials: such as the processes of grinding, crushing, or stamping, where the material intervenes between two acting surfaces, by which it is held or supported at the time of being operated upon. The writer was led to design the disintegrating machine in consequence of practically experiencing the difficulty and imperfection attending the mode of pulverising artificial manures, such as superphosphate of lime, by the means then available for the purpose. Owing to its containing some combined moisture, this material is liable to get into a pasty condition when crushed; but he found that when a lump of it was struck a rapid blow by a stick, whilst thrown up in the air, it became completely shattered, bursting into minute fragments as though under the action of some explosive force. The way in which this result is effected in the disintegrator is by causing the pieces of the material to fly through the machine with the projectile impetus communicated to them by the centrifugal force resulting from rapid rotation; and these flying pieces are struck in mid air with reiterated blows, delivered with extreme rapidity in alternately opposite directions by a succession of rotating beaters, and are thus shattered by collision against the unarrested beaters, which encounter them in the opposite direction to that in which they were moving. As the particles struck can offer no resistance but

that which is due to their own inertia, without the aid of any solid abutment to support them when receiving the blows, no friction or compression is produced, and the moving power of the beaters is not needlessly neutralised and absorbed by any such unyielding abutment.

The disintegrating mills, which were originally designed for granulating superphosphate of lime when it had conglomerated into a pasty mass after being partially dissolved by vitriol, were subsequently applied successfully to granulating clays, ores, and other minerals. As however the recent adaptation of the disintegrator to a flour mill forms by far the most important application, this will here be described first.

The Disintegrating Flour Mill is shown in Figs. 1 to 3, Plates 1 and 2; Fig. 1 is an external side elevation of an entire machine, 7 feet diameter; Fig. 2 a transverse section taken through the centre of the machine; and Fig. 3 a longitudinal section of the two rotating discs with a portion of their respective shafts; Fig. 4, Plate 3, shows a portion of the transverse section to a larger scale.

The machine consists of a pair of circular discs A and B, Fig. 1, rotating in contrary directions upon two shafts D and E situated in the same line; the opposing faces of the discs are studded with a series of short projecting bars or beaters, arranged in successive concentric rings or cages; and the rings of beaters fixed in one disc intervene alternately between those fixed in the other disc, and revolve in the opposite direction. The solid circular disc A, keyed on the left-hand shaft D, as shown in Fig. 3, carries the third cage or ring of beaters (counting outwards from the centre), and also the fifth, seventh, ninth, and eleventh cages, all of which therefore rotate the same way. On the right-hand shaft E is keyed a small inner disc C, into which are riveted the bars of the two innermost cages of beaters, their other ends being riveted into the right-hand annular disc B, which is thus carried by them; this annular disc in turn carries the fourth, sixth, eighth, and tenth cages, which with the two innermost all rotate in the contrary direction to the cages carried by the left-hand disc A, as indicated

by the arrows in Fig. 4. The two innermost cages are both fixed in the same disc so as to rotate both in the same direction, in order thereby to ensure distributing the material more effectually through the machine by the centrifugal force. The cages of beaters are of successively increasing diameters, and consist of $\frac{1}{2}$ inch round steel bars, with clear spaces between of about 2 inches in each direction; the outer ends of the bars in each cage are tied together by a ring, as shown in Figs. 2 and 3, and to a larger scale in Fig. 9, Plate 6.

The two shafts D and E are placed in a line, their rounded ends just touching each other, or nearly so, in the centre, Fig. 9; everywhere else ample clearance is allowed for enabling the two halves of the machine to rotate entirely independent, acting only in unison as auxiliary to each other in pulverising the material that is being operated upon. The shafts are each mounted in two plummer blocks on a heavy square bedplate; and a driving pulley is keyed either in the middle of each shaft or at its outer end, as may be found most convenient for the driving straps, one of which is a crossed strap and the other an open one, so as to drive the two halves of the machine in opposite directions. The revolving cages of beaters are enclosed within an external casing F, Figs. 1 to 3, which has a centre opening in the right-hand side, corresponding with that of the annular disc B.

The grain is delivered down a fixed shoot G, Figs. 1 and 3, through the centre opening of the outer casing, into the innermost cage, from which it is instantly projected through the machine, and delivered in a radiating shower from every portion of the circumference into the outer casing, in the form of a meal, similar to that thrown out by the ordinary millstones; to this state the grain is reduced almost instantaneously by being dashed to the right and left alternately by the bars of each of the successive cages revolving in opposite directions at a very high speed. As it falls to the bottom of the casing, the meal is continuously removed by the ordinary rotating screw H, Fig. 2, used in flour mills; it is then passed through the usual bolting machines to separate the bran, and subsequently through silk dressing-machines to separate the fine flour from the semolina. The latter is then winnowed by an exhaust

current of air in a machine for that purpose, so as to free it from all finely powdered bran, and is afterwards ground between millstones, of which three or four pairs are kept for the purpose; the flour resulting from it is added to the fine flour produced at the outset by the disintegrating flour mill, and to ensure perfect intermixture the two are then passed through the silk dressing-machines together.

The course of a particle through the disintegrator is illustrated in the diagram, Fig. 5, Plate 8; the circular arrows show the reverse direction in which the alternate cages rotate, and the straight arrows at different angles show the zigzag course of a particle of material as it flies off at a tangent from each cage, being struck alternately to the right and left and projected thereby at a speed equivalent to that at which the bars of the cage last striking it were rotating; the force of each blow is thus increased by the momentum of the material, which is moving in each case in an opposite direction to that of the beaters it next meets with. As the material becomes more finely pulverised in its course outwards through the machine, and the particles have consequently less inertia of themselves to act as an abutment for receiving the blows of the beaters, a greater force of blow is necessary, in order to continue the pulverising process. This increased force is supplied by the higher velocity arising from the larger diameters of the successive rings of beaters which the material meets with in its passage outwards. The machine is driven at a speed of about 400 revolutions per minute; and the outermost ring being 6 ft. 10 ins. diameter, the last beaters have a velocity of 140 feet per second, or about 100 miles per hour; this is double the velocity and consequently gives four times the force of blow of the innermost ring of beaters, the force of blow being proportionate to the square of the velocity.

In this mode of action, by the free blows of the beaters upon the material, the friction and compression between the machine and the material, which are involved in all grinding, crushing, or stamping processes, are avoided, this mill being the only machine that does not act upon the material between a pair of surfaces; and as the beaters do not strike upon any solid abutment, the whole power

employed is usefully expended in pulverising the material, excepting only the portion of the power absorbed by the resistance of the air to the rotation of the beaters. This mill has the advantage of unusual freedom from risk of injury by the accidental introduction of any unsuitable substances, such as pieces of metal; any such substances are freely ejected by the centrifugal force, without the possibility of any squeezing action being exerted upon them. The machine has not any tendency to become choked, nor are any working parts liable to get out of order, as the two sets of beaters revolve entirely clear of each other, and the beaters never come in contact with anything but the free particles of the material that is being pulverised. In the case of the flour mill, the beaters being of steel, and coming in contact only with the grains of wheat, are not subjected to any perceptible wear, and keep at work continuously without ever requiring any dressing or attention. But with the ordinary millstones, a surplus supply of stones, amounting to one-eighth of the whole number, has always to be kept out of work, to allow for the dressing and sharpening which is usually required to be done upon each pair of stones after about every four days' work.

Two of these disintegrating flour mills are in regular work for 22 hours per day at the Bonnington Mills of Messrs. Gibson and Walker at Edinburgh, and have proved completely successful during a year's continuous work. The percentage of flour produced from the same wheat is practically the same as with millstones; but the quality of the flour is found to be decidedly superior, in consequence of the freedom from the compressing action that accompanies grinding by millstones. The flour is delivered in a finely granular state, without being "killed," as it is termed, or rendered dense and partly impervious to water by too fine grinding under frictional pressure; it consequently absorbs more water when used, and is of the quality esteemed for baking into a lighter and better-keeping bread. The bran is also more perfectly separated from the flour in the subsequent dressing process, in consequence of having been scaled off from the grain in larger flakes and less broken up than in grinding by stones.

The work regularly got through by each machine of 7 feet diameter amounts to 20 quarters of wheat or 160 bushels per hour; which would require as many as twenty-seven pairs of ordinary millstones in full work, taking the average duty of each at 6 bushels per hour. A further supply of three or four pairs of stones under the dresser's hands would be required for keeping that number at work; but these are compensated for by the three or four pairs of finishing stones which are used with the disintegrating mill for grinding the granular portion called semolina, as before explained.

The ultimate result with the disintegrating mill at Edinburgh, when working upon Scotch wheat alone, after the fine flour produced direct from the mill has been mixed with the ground semolina, is $57\frac{1}{2}$ per cent. of finest flour, worth *5s.* per sack more than flour from the same wheat ground by millstones. The latter however give a total of 68 per cent. of fine flour, but of less value by *5s.* per sack. The remainder of the flour from the disintegrator is $10\frac{1}{2}$ per cent. of an inferior quality, worth from *5s.* to *10s.* per sack less than best millstone flour; and taking this at its lowest value, the following is the comparative total value of the flour obtained from 100 sacks of the same wheat by the two processes:—

	£	s.	d.
With the Disintegrator			
$57\frac{1}{2}$ sacks of finest flour at *53s.* per sack . .	152	7	6
$10\frac{1}{2}$ „ inferior „ *38s.* „ . .	19	19	0
Total . .	172	6	6
With Millstones			
68 sacks of fine flour at *48s.* per sack . . .	163	4	0
Difference £	9	2	6

There is thus a difference in favour of the disintegrator of £9, or $5\frac{1}{2}$ per cent. in the item of marketable value of the flour. This gain is equivalent to an extra profit of £16 on each 100 quarters of wheat (a sack being 280 lbs. and a quarter 496 lbs.); and the rate of production being 20 quarters per hour, it will be seen that the annual value is a very important amount.* In addition there is the saving in power and labour employed, in

* The profit would be less in amount on the harder and drier qualities of wheat, which are higher priced than the softer Scotch wheat.

space occupied, and in cost of repairs; and as regards the last item, the repairs have been practically nothing with the disintegrating flour mill during the twelve months' constant work of 22 hours per day, whilst with millstones a heavy cost is constantly incurred in stone dressing.

The disintegrating flour mills at present in use are made with fourteen rotating cages, as shown in Fig. 9, Plate 6, instead of only eleven cages, as in Figs. 1, 2, and 3; but the fourteen have been found to be more than are necessary, while one mill also in use that has only eight is found scarcely sufficient. The beaters are also made much shorter now than those hitherto used, being only 3 inches long in the clear, as in Fig. 3, instead of 8 inches as in Fig. 9, in order to bring the discs so much nearer together, and thereby diminish proportionately the loss of power in churning the air, which was found in the experiments made at Edinburgh to be more serious than had been at all anticipated. The capacity of the machine with the reduced width will still be far beyond the requirements, when operating on only 20 quarters of wheat per hour; for the velocity of the material in passing through the mill is so great that a mere fraction of a second elapses from entrance to exit of any given particle, and hence there can never be more than a few handfuls of the material in the machine at any one instant. In other new machines at present making, the bars being now but little more than mere pegs, the tie rings at their extremities are dispensed with, as shown in Fig. 10, Plate 7, being no longer necessary for so light and small a material as wheat. By the omission of these tie rings the successive circles or cages of beaters can be placed much nearer the circumference, whereby their respective diameters and consequently their speeds in feet per second are proportionately increased. The machine is remarkable for its simplicity of construction and non-liability to deteriorate in efficiency in consequence of wear, and for its large production and the superiority of its work; and also for the very small space it occupies, in comparison with that taken up by the twenty-seven pairs of ordinary millstones which are required to perform the same amount of work.

The Mineral Disintegrator, of which the flour mill was constructed as a modification, is shown in Figs. 6 to 8, Plates 4 and 5, and is used for pulverising various mineral substances, such as artificial manures, zinc ores, rock asphalte, &c. It is made of much greater strength in the beaters than the flour mill, and of smaller diameter, being only $4\frac{1}{2}$ feet instead of 7 feet diameter, and having only four cages of beaters instead of eleven or fourteen. The two discs are both carried from the same side of the machine, the shaft of the left-hand one being made tubular, and that of the right-hand disc carried through it without touching it, as shown in Fig. 6; by this arrangement the central opening through which the material is fed into the machine is left entirely unobstructed by the driving straps, and the material can be thrown into it by a shovel. This machine is not so well adapted for high speeds of working as the flour mill, on account of the great size of the bearings of the hollow shaft. The speed it is driven at varies from 350 to 500 revolutions per minute, according to the hardness of the material that is being pulverised, the degree of fineness to which it has to be reduced, and the driving power available. A larger size of the machine is made, of $6\frac{1}{4}$ feet diameter, and also a smaller size of $3\frac{1}{2}$ feet diameter.

When a soft and adhesive material is operated upon, a portion adheres to each beater, and the machine sometimes, though very rarely, requires cleaning after ten or twelve hours' working. As the material adheres only to the back surface of each bar, while the front remains clean, the machine is readily cleaned by running it backwards for a short time, where there is the means of reversing the driving power; or the cleaning is effected without reversing, by throwing in while at full speed one or two cwts. of some brittle and dry material.

The $4\frac{1}{2}$ ft. machine is capable of pulverising 5 to 15 tons of material per hour, according to the nature of the materials and the degree of fineness to which they are reduced; the amount of power required to drive the machine, which varies with different materials, is from 10 to 25 horse power.

The mineral disintegrator is in successful use for pulverising a variety of different materials. In a less perfected form it has been several years in use for breaking up the cakes or conglomerated lumps of artificial manures after manufacture, and the bone ash and mineral phosphate from which they are made, reducing the product to a fine granular powder for sowing with the grain. It is also used for pulverising the coal and pitch from which artificial fuel is manufactured, and the hard rock asphalte employed for making roadways; and in these applications the peculiar action of the disintegrator is found particularly advantageous in breaking up and pulverising the material by free blows, avoiding all the compressing action that occurs in the processes of grinding or crushing, which causes a tendency to clog the machines on account of the tough nature of some of the material operated upon. Raw clay for the manufacture of fire-bricks and sanitary tubes is prepared by the disintegrator, both dry as dug from the pit, and in the wet and weathered state; and burnt brick and earthenware are pulverised by it for mixing with the clay. The ores of zinc, namely blende and calamine, are broken up for smelting, and other hard materials, such as gold quartz; also cattle food, such as locust beans, oil cake, &c.

The disintegrator is also very efficient for mixing as well as for pulverising; the action of the successive cages of beaters revolving in opposite directions and expelling the mixed materials all round the circumference is a remarkably perfect means of effecting a thorough mixture. It is in extensive use in sugar factories for mixing the various shades of moist sugars into the required uniform hue; and it is also used for mixing the lime, sand, and hair, for mortar making, in which application it has the advantage when driven at a moderate speed of being free from the objection of reducing the sand to fine powder, as is done by edge-runner mills. A further extension of its application may perhaps be effected for finely granulating metals in a melted state, by employing a machine revolving horizontally, without an external casing, so as to project the drops of melted metal from the

circumference and allow them to fall into water, for the production of lead shot or other purposes.

Mr. Carr showed models of the disintegrating flour mill and the mineral disintegrator, with a variety of specimens of different materials pulverised by the latter, including blende and calamine, fireclays, potsherds from glassworks, &c.; also samples of the wheat meal as produced by the disintegrating flour mill, and of the fine flour, semolina, and bran, when separated from the meal by the ordinary bolting or dressing machines. In describing the models he drew attention to the circumstance that, as the two discs with their respective cages of beaters revolved quite clear and independent of each other, there was no friction between them, and the only friction to be overcome in the machine was simply that of the bearings of the two shafts; and that, in consequence of the discs revolving in opposite directions, each particle of the material passing through the machine encountered the successive beaters at double the velocity at which they were actually running, being struck by them alternately in opposite directions. The disintegrating flour mill at present in use, as represented by the model exhibited, contained fourteen cages of beaters and as many as 1000 beaters in all, of 8 inches length; but that number of beaters and also their length were found to be more than was requisite, causing the loss of power in churning the air within the machine to be greatly increased beyond the amount that was unavoidable; this loss he believed would now be materially diminished by shortening the beaters and so bringing the two discs closer together, and he expected it would be found possible to bring them very much closer still, and thereby further to reduce this loss of power. With the beaters 8 inches long the strain produced upon them by the centrifugal force when the discs were revolving at a high

velocity was so great that it was necessary to tie their outer ends together by rings connecting all the beaters in each circle; these rings were of crucible steel, and were made in the same way as weldless tyres, each being made originally broad enough on the circumference to allow of dividing it into three rings of the same dimensions. At the speed originally intended of 800 revolutions per minute, the tensile strain produced upon the outermost ring by the centrifugal force was calculated to amount to nearly 10 tons per square inch; but 400 revolutions per minute were now found by experience to be ample for the production of flour, with discs of 7 feet diameter; at that speed he believed any individual grain of wheat was only a fraction of a second in passing entirely through the mill and issuing in the state of meal. Instead of the fourteen cages of beaters originally employed, eleven were now found to be quite sufficient, and the beaters were placed rather further apart, 2 inches clearance being allowed them in every direction, instead of the original $1\frac{1}{2}$ inches; in the mineral disintegrator they were sometimes put as far as $4\frac{1}{2}$ inches apart, and this increased distance was not found at all to diminish the degree of fineness to which the minerals were pulverised. In the disintegrating flour mill duplicate driving pulleys on the shaft of each disc were provided for the purpose of accommodating the straps to any situation in which the machine might have to work; when the countershaft driving the machine was situated at a lower level, it would generally be more convenient to have the straps upon the overhung pulleys at the ends of the disc-shafts; but when the driving countershaft was overhead, the straps could go round the inner pulleys, which was preferable; in either case one of the straps was of course required to be crossed and the other open, for driving the two discs in contrary directions.

The President enquired how large were the pieces of material that were supplied into the mineral disintegrator, and what was the power required to work the machine in pulverising any of the minerals of which specimens were exhibited.

Mr. Carr replied that the size of the pieces of material put into the machine depended upon their hardness and upon the strength of

the machine employed for the work. The hardest material he had yet tried to pulverise was potsherds from the large pots employed in melting the materials for glass making; when these pots became cracked in working, they were rendered useless, and had to be broken up and pulverised for moulding with fresh raw fireclay into new pots. The potsherds were about as hard as granite, and very tough, and were therefore supplied into the machine in pieces not larger than the specimen exhibited, about 2 or 3 inches cube; and they were completely pulverised in once passing through the machine, as shown in the specimen exhibited of the powdered material produced. In pulverising zinc ore, a disintegrating machine of 4 feet 6 inches diameter driven by an engine of 15 horse power was found to pulverise 15 tons per hour to a granular powder of an exceedingly fine and uniform grain.

Mr. E. H. Carbutt mentioned that the Bradford Flour Mill Co. had one of the disintegrating flour mills, which had now been at work there about three months, and he believed they were very well satisfied with it. A certain proportion of the flour produced, after it had been screened, had to be passed through dressing stones for grinding it fine, as named in the paper; and he had also noticed that the bran had a good deal of flour adhering to it, and would therefore have to be put through the machine again in order to separate this. Some difficulty had been experienced in keeping the bearings of the machine cool, and it had been necessary to take off the top brasses and run water over the bearings while working, in order to cool them sufficiently.

Mr. Carr said it was only while the machines were new that the bearings were liable to heat, and they speedily improved in that respect. There was always flour adhering to the bran first delivered from the machine, as seen in the sample exhibited of the bran; this flour was separated from the bran by passing it a second time through the machine, by which the bran was thoroughly cleaned and the flour obtained separate from it by bolting, as shown in the second samples exhibited of the bran and of the flour. The semolina produced by the disintegrating flour mill employed at Messrs. Gibson and Walker's mill at Edinburgh, after separation from the fine flour

and winnowing free from finely powdered bran, was also ground into fine by two or three pairs of millstones, and was mixed by bolting with the fine flour first produced.

Mr. J. H. Perks enquired what amount of applied power was utilised in working the disintegrating flour mill, and what was found to be the loss of power caused by the resistance of the air; he suggested that this loss might partly be obviated, as in the case of a centrifugal fan, by putting the external casing close enough to the circumference of the discs, so that the air should be carried round inside the casing by their revolution.

Mr. F. J. Bramwell said that on the occasion of the British Association Meeting in Edinburgh last August he had had an opportunity of seeing the disintegrator at work at Messrs. Gibson and Walker's Flour Mill, where the greatest facilities had been afforded by the proprietors for investigating its action, the whole of the other machines in one section of their large mill being stopped while indicator diagrams were taken by Mr. Edward Easton and himself. This section of the mill was driven by a compound-cylinder engine, which also drove a large number of other machines; all that it was possible to throw out of gear was disconnected, but nevertheless there was a great amount of shafting which could not be uncoupled. The disintegrator was therefore disconnected in the first instance, and the power required to drive the shafting alone was thus ascertained; and this power to overcome the shafting friction was deducted from the indications obtained in the subsequent experiments with the disintegrator. On considering the question of the power required to set the air in the disintegrator in motion, it had occurrred to him that the machine must act in a very different way from the action of a fan, because of the two sets of cages running in opposite directions, and thus producing conflicting motions in the air; so that whether the casing of the machine were closed or not closed, much power must necessarily be consumed in this conflict. Although the whole quantity of air contained within the machine, which had beaters 8 inches long, weighed only about 2 lbs., yet the power expended in simply

agitating that weight of air in the manner in which it was dealt with by the machine turned out to be very great. In order to ascertain correctly the power absorbed by this action upon the air, he had had the machine driven at the usual speed of about 400 revolutions per minute, pulverising 15 quarters of wheat per hour, and had found the power then consumed was 123 indicated horse. The machine was next made to run perfectly empty at the same speed, and the power consumed was found to be 63 horse. The driving strap of one of the discs was then thrown off, and the two discs, having been securely lashed together with cords round the beaters, were driven at the same speed as before but both in the same direction, so that the whole machine revolved like an ordinary centrifugal fan, without the reversed action of the second set of beaters; the power then consumed in driving the machine was only 19 horse. It therefore appeared that the difference between 63 and 19 horse power, namely 44 horse power, was expended in simply churning the air that was in the machine; this was certainly a very interesting and remarkable result.

An experiment was then made to ascertain the power required to pulverise 20 quarters of wheat per hour, which was found to be 145 horse; and as in the previous experiment 15 quarters per hour had taken 123 horse, the difference between these two results gave 22 horse power for pulverising the additional 5 quarters of wheat per hour, or $4\frac{1}{2}$ horse power per quarter of wheat ground per hour; the pulverising of the 15 quarters per hour had consumed 123 less 63, or 60 horse power, being only 4 horse power per quarter. These amounts were so very small, compared with the power required in grinding by ordinary millstones, that there could be no doubt about the large saving attendant on the use of the disintegrator, even after deducting the power shown to be lost by agitating the air in the machine, and after also allowing for the fact that the machine did not complete the grinding of the whole of the flour at one operation, but produced a large proportion of semolina which required to be ground afterwards between stones. There was also a very important saving in the first cost of the machine, in the space occupied by it, and in the labour and

maintenance attendant upon its working. In all the experiments he had made with the machine, the bearings worked perfectly well and continued quite cool.

In corroboration of the statement respecting the large amount of power required to churn the air, he might mention he had been informed that when the machine was first put to work it had been driven at 700 revolutions per minute, and in running empty at that speed without any grain it had absorbed the whole power of the engine, and the temperature of the external casing had risen to about 110° Fahr. in two or three minutes, notwithstanding that there was a free passage for the air through the machine. He was glad to see an endeavour was now being made to remove the difficulty arising from the resistance of the air by the very simple expedient of diminishing the width of the machine. An idea that had occurred to him for obviating that difficulty had been to work the machine in a partial vacuum, or even in an atmosphere of hydrogen which would have only one fourteenth of the weight of the air; but bringing the discs closer together would clearly have the same effect of diminishing the total weight of air contained within the machine. No doubt this was the simplest way of removing the difficulty, and it was attended with the advantage that, in consequence of the beaters being made so much shorter, the strengthening rings connecting their outer extremities could then be got rid of, thereby simplifying the construction of the machine in the manner shown in Fig. 10. He enquired whether any of these narrower machines had yet been got to work; and he suggested that it would be of much interest if the same experiments which he had tried on the present wide machine were repeated on the narrower one, so as to ascertain to what extent the loss of power due to the churning of the air was diminished by bringing the discs closer together.

He had first seen the disintegrating machine some years ago, used for pulverising potsherds, and had been very much struck by the principle of its action, which appeared to be perfectly new. He did not know of any other machine for pulverising materials where the only abutment against which the machine acted was that presented by the inertia of the particles of the material operated

upon; in ordinary millstones, edge runners, rumblers, stampers, or crushers, and he believed in all other contrivances by which materials were reduced to powder, an abutment was provided by one part of the machine, against which the material was pressed by some other part of the machine, and the material was crushed or pulverised by coming between these two parts. In the disintegrator however the whole force of the machine was expended directly upon the material itself, which was knocked about right and left with a succession of rapid and violent blows until it was completely pulverised. This construction of machine appeared to him to be eminently satisfactory for general adoption on account of its compactness and durability; and an important practical advantage attending its use was that its efficiency in working was not impaired by wear, as was the case with most other machines; the beaters might decrease in size until they actually broke, and yet so long as they remained unbroken the extent of their wear did not signify, and they would still do their work as effectually when worn as when new, because they had only to strike blows upon the material, which they could do equally well, however much they might be reduced.

Mr. CARR said several of the narrower flour mills, intended to diminish the loss of power from the resistance of the air, were now in course of construction, but they were not yet in operation. Although they would be considerably reduced in width, he considered their capacity would still be beyond the requirements of their working, in consequence of the very great speed at which the grain passed through the machine and issued in the form of meal.

Mr. E. A. COWPER observed that he had had one of the 3 ft. 6 ins. machines in use and also one of 6 ft. 3 ins. diameter for artificial manures, and they had worked very satisfactorily. In the larger machine the two driving shafts were arranged independently and opposite each other, the same as in the disintegrating flour mill, instead of making one of them hollow and carrying the other through it, as in the drawings shown of the mineral disintegrator; the bearings were found to work cool, and there had not been any

occasion for running water over them as previously referred to. The quantity of material broken up by the machines was certainly very great. When working on artificial manures they became clogged with the phosphate of lime, and to clean them he had tried putting some hard dry material through the machine, but this did not answer perfectly; he thought the best plan was simply reversing the machine, when the backs of the beaters became the fronts, and they were thus cleaned by the further working of the machine. There might possibly be a little trouble in reversing the machine for cleaning, unless there were the means of readily reversing the engine for the purpose; but however frequently the cleaning had to be done, any inconvenience attending the operation was far outweighed by the very large amount of work performed by the machine. The samples of flour he remembered seeing at the Oxford Meeting of the Royal Agricultural Society in 1870 from the disintegrating flour mill were not in so perfect a condition as the samples of flour now produced, which were very good, and much superior to those obtained from the earlier machines; he considered the new mill was an important improvement in grinding. One of the mineral disintegrators he understood was employed at Boston in the United States for breaking up Missouri Mountain iron ore, which was a tolerably tough material, but was well broken up by the machine. A suggestion occurred to him with regard to the beaters of the disintegrator, whether they would not be better to be made square instead of round, and to be fixed with their flat sides radial. With the present round beaters, if a particle of material struck them on either side of the centre line, it would glance off without receiving the full force of a direct blow, and the efficiency of the beaters would thus be diminished. Square beaters on the other hand would give a full blow upon all particles striking anywhere upon their flat faces; and he thought the effect would be that three or four of the rings of beaters in the flour mill might be dispensed with by the use of square beaters.

Mr. Carr said he had not tried the use of square beaters in the disintegrator, but although they were perhaps more correct in principle than the round bars, he did not think much advantage

would be gained by their adoption, because there would still be the liability of the particles of material striking the corners of the bars instead of their flat faces; it was therefore preferable he thought to make the bars round, as the simplest and safest plan. A large number of the mineral disintegrators were now in use in America, where they had been introduced about five years ago.

Mr. F. W. Webb enquired whether the disintegrator had been tried for breaking up a hard friable metal such as spiegeleisen. He considered it would be a very useful machine if it could break up spiegeleisen so as to supply it to the steel converters in the Bessemer process in a pulverised state, instead of having to melt it beforehand as was at present the case.

Mr. Carr believed the disintegrator had not yet been tried upon spiegeleisen; but zinc ore and crucibles for glass melting were readily pulverised by it, as shown by the specimens exhibited, and harder materials than the latter especially could scarcely be found among those which were required to be pulverised.

Mr. T. Greenwood observed that he had seen some of these machines at work in France two or three years ago in the neighbourhood of Paris, where they were used for breaking up a mixture of lime and clay for making the best roman cement. The material was found at that place as a natural mixture, and had to be ground very fine, after which it was made into bricks, burned, and then broken up and ground fine again, ready to be used as cement. The difficulty of pulverising the raw material in the first instance had previously been very great, as it was a damp and tough substance, greatly resembling putty in appearance and stickiness; he had brought a quantity of it over to Leeds and had tried crushing it with edge-rollers, but it stuck to the rollers and was very difficult to work in that way, while any preliminary process of drying to prepare it for crushing more readily would have added too much to the expense of the manufacture. The disintegrator he had seen at work in France certainly struck him as a very remarkable machine, and was the only machine he knew of that would successfully pulverise such a material as that cement. The raw material dug from the rock was broken into large lumps and thrown direct into the

machine, which was about 4 feet diameter with four rings of beaters; it was driven at a great speed, and pulverised the material very completely.

Mr. CARR said the disintegrator had been four years in use in France, and there were now nearly a hundred of them at work in different parts of the Continent for a great variety of purposes.

Mr. A. PAGET remarked that with the disintegrating flour mill 15 quarters of wheat per hour was the smallest quantity which had been mentioned as being pulverised by the machine; and although for a mill in a large town such a rate of production would no doubt be requisite, he thought it would be far beyond the wants of an ordinary country mill. He enquired therefore whether a machine had been constructed suitable for producing a smaller quantity, and what was the smallest size of the disintegrator that had yet been made as a flour mill; if it were intended to come into general use in country districts, he considered it would be requisite that the capacity and consequent power required should be much smaller than that of the machine of which the particulars had been given in the paper. If the mill were employed in producing a smaller quantity of flour than its size was capable of yielding, the proportionate loss of power by churning the air would of course be increased; and a smaller mill taking less power would therefore be desirable where the required production was necessarily limited to a small quantity only.

Mr. CARR replied that he was now making two flour mills of 5 feet diameter and containing only nine cages, and one of 7 feet diameter containing eleven cages, all with the bars greatly shortened, for the express purpose of diminishing the action upon the air and producing a smaller quantity of flour. It would not be advisable he considered to go much below 5 feet diameter for the flour mill, because the lineal speed of the outermost beaters could not be reduced without interfering with the efficiency of the machine for the production of flour, and therefore as the diameter was diminished the number of revolutions per minute had necessarily to be increased proportionately, which increased the difficulty of keeping the bearings cool. The only further means of adapting the mill to a smaller production of

flour would be by still further shortening the beaters and bringing the discs still closer together, so as to reduce the capacity of the machine; and the power consumed in pulverising the grain would of course be diminished in proportion to the reduced production of flour and the smaller quantity of air churned in a narrower mill.

Mr. F. J. Bramwell mentioned that in the experiments he had made with the disintegrating flour mill at Edinburgh one of the points he had endeavoured to ascertain was the difference in the loss of power when the machine was driven empty at varying velocities. The lowest speed at which it had been possible to drive the engine steadily enough for arriving at any definite results was 12 revolutions per minute; and from the indicator diagrams taken at this and several higher speeds, up to the ordinary speed of running, it was found that the power uselessly expended in churning the air increased about as the cube of the velocity, in accordance with theory. The experiments were all made under the same conditions, as to access and discharge of air, that prevailed in ordinary working.

Mr. E. A. Cowper observed that, although the closing of the external casing would of course not prevent the loss of power in agitating the air, because of the contrary motion of the two sets of cages, yet the amount of the loss he considered would be somewhat less when the casing was closed than when the air was free to escape from the circumference of the mill, because in the latter case a much larger quantity of air would be passing through the machine from the centre to the circumference and undergoing the action of the beaters. The main point of importance in the closing of the casing seemed to him to be that the quantity of air passing through the machine should be limited to the least that was possible, only enough being allowed to pass through for keeping the machine and flour cool and dry during the working.

Mr. F. J. Bramwell remarked that by the churning of the air within the machine a large amount of power was being converted into heat, and if there were not air enough allowed to pass off continuously from the machine he believed the meal would get so hot as to be prejudicial to the flour.

Mr. SAMPSON LLOYD said he had seen the mineral disintegrators at work at Swansea, pulverising small coal for the manufacture of artificial fuel, and also calamine or zinc ore, which was a very hard mineral. The only disadvantage in breaking up such hard minerals in the machine was that the beaters wore out in the course of a few weeks, and when one bar broke it was apt to break others out also; and in some cases he understood these breakages had been found so serious as almost to cause the machine to be abandoned. For softer materials the disintegrator answered very well; and it seemed to him a very excellent machine for all purposes of pulverising.

The PRESIDENT enquired what was usually found to be the durability of the beaters in the mineral disintegrators when employed in breaking up hard material, and whether they were made of steel in all the machines.

Mr. CARR replied that in machines employed regularly every day in breaking up a hard material like calamine at the rate of 15 tons an hour the bars were found to last he believed about six or eight months before any breaking occurred, being made of steel, $1\frac{1}{2}$ to 2 inches diameter according to the hardness of the material to be pulverised. At Messrs. Dillwyn's smelting works at Swansea, where six of the mineral disintegrators were now in constant use for breaking up zinc ores, the bars of some had been replaced several times, but this had not been considered any objection to the machines when the quantity of work performed by them was taken into account. Even when several of the bars had been broken out, no difference was perceptible in the fineness of the material pulverised, and the machine only required to be driven a little faster to compensate for the smaller number of bars; the sooner however they were replaced the better, as the balance and consequently the smooth working of the machine would otherwise be interfered with. When a bar broke within the machine, it had of course to fight its way out through the outer rings of beaters, and might perhaps break a few other bars in doing so, but this was not always the case. There were only four rings of beaters in the mineral disintegrators, and when any of the bars broke in the outside ring they were thrown off without damaging any of the others; it was only when a bar broke in one

of the three inner cages that there was a possibility of its doing any injury in making its way out. In the disintegrating flour mill the bars were also made of steel, for the purpose of getting them as small and light as possible, on account of the very high speed at which the mill was driven.

The PRESIDENT remarked that the working capacity of the disintegrator appeared to depend upon the length of the beaters, the diameter of the machine being determined by the nature of the material to be pulverised or by the speed requisite for the purpose of effecting its disintegration by reason of its inertia; and he enquired whether in the disintegrating flour mill at Edinburgh, with beaters 8 inches long, a greater quantity than 20 quarters of wheat per hour had been pulverised, and what was considered the maximum result which a mill of that size would be able to produce.

Mr. CARR replied that 20 quarters of wheat per hour was the greatest quantity that had been pulverised by the mill at Edinburgh, but only because this produced as much flour as there was the means of dressing in the same time; the mill itself would no doubt be able to produce a much greater quantity, but the limit of its production had not been ascertained. So far as weight was concerned, the 20 quarters of wheat per hour amounted to less than 4½ tons, whilst the mineral disintegrator pulverised 15 tons of calamine per hour; but on account of the lightness of the flour it occupied a much greater bulk, and the flour mill at Edinburgh had therefore been made of the width shown, in order to ensure ample capacity for the required production, the circumstance not then being known that if the capacity were too great for the requirements so much power would be needlessly wasted in churning the air.

The PRESIDENT enquired whether supplying the grain more rapidly to the mill was found to cause a larger proportion of semolina to be produced, on account of the blows being softened by the striking surfaces becoming encumbered with the meal.

Mr. CARR replied that the proportion of semolina produced was not found to be affected by the quantity of grain passing through the machine; but it did depend on the speed at which the machine itself was driven, for the higher the speed the greater was the

percentage of fine flour and the smaller the proportion of semolina; and this gave the means of altering the proportion by adopting a different speed for the machine.

Mr. T. Greenwood enquired whether in any of the disintegrating flour mills the speed had been ascertained at which the flour would become heated to an objectionable temperature.

Mr. Carr replied that a speed sufficient to heat the flour injuriously had not been reached in any of the disintegrating flour mills, and the highest temperature to which the air had been heated in the mill, when running empty and at nearly double the speed now used, was only about 110° Fahr., or little more than the temperature of a summer day in the sun; if the flour was at all damp, even that extent of heating would be beneficial for drying it and thereby rendering it less likely to go sour.

Mr. T. Greenwood said that in grinding flour by means of fluted steel rollers he understood the flour was not heated at all, and that consequently no fermentation took place and the flour would keep for a great length of time. At a large mill at Pesth in Austria, where 50 tons per week were being ground in that way, he had been shown flour which had been kept for ten years in a dry storehouse, and continued perfectly good on account of not having been heated; but he doubted whether any flour ground by stones would keep good so long. In that mill there was a series of about sixteen of the steel rollers placed one above another, and the whole of the grain passed alternately backwards and forwards between all of them in succession, making fifteen times of passing through; the effect was that the flour was not heated at all, as it was so short a time between the rollers, and was not subjected to the continued rubbing that it underwent between millstones.

Mr. Carr said the flour would not become discoloured by scorching at any temperature below 212° Fahr., and there was therefore no risk of its being so injured if heated to 110°. With regard to fermentation, this arose not from the brief application of artificial warmth, but from the "sweating" resulting from the presence of too much moisture; and diminution of the moisture would therefore diminish the tendency to ferment.

Mr. E. H. CARBUTT observed that 110° had been mentioned as the temperature to which the mill and casing were heated when the mill was running empty and was only churning the air; and the temperature would therefore evidently be considerably lower when the flour was passing through, because a portion of the heat would be carried off continuously by the flour.

Mr. CARR remarked that the small amount of moisture contained in the flour also rendered much of the heat latent by evaporation; and moreover, as the sheet-iron casing had time to accumulate the heat from the air, it was reasonable to suppose it would always be warmer than the flour, which was only so briefly exposed to the heating.

Mr. F. J. BRAMWELL observed that the introduction of Mr. Bovill's plan of aerating the flour by means of a fan blast, in grinding with millstones, had had for its object both to dry the flour by the current of air taking up the moisture, and also to keep the flour cool throughout its passage between the stones, and thereby prevent the liability of its becoming sour; and in the disintegrating flour mill the material was so thoroughly and freely knocked about, and was exposed all the time to such a strong current of air, that he thought a still better aeration and drying were obtained than were possible when the flour was confined between millstones. The temperature of the flour he believed was sensibly lower in the disintegrating flour mill, for on feeling it by hand as it came from that mill he had found it decidedly cool as compared with that usually delivered from ordinary millstones.

The plan which had been referred to as in use at Pesth of grinding corn by means of steel rollers was known in England as Buchholz's plan, and was in use he believed in Liverpool. Another Pesth system of grinding was also in use at the North Shore Flour Mills, Liverpool, consisting of six pairs of stones with as many sets of intermediate dressing apparatus: the whole of the grain was passed through the first pair of stones, but was only very slightly ground by them, and then underwent a complete dressing, after which the residue was passed through the second pair, and so on through all the six pairs of stones, the dressing being

repeated between each grinding; the semolina was got out in large quantities at about the third or fourth pair of stones. The results appeared to be highly satisfactory, notwithstanding that in this instance, owing to want of space, there were only six pairs of stones, instead of the nine pairs requisite for fully carrying out the system; and he had no doubt that when completely carried out on a large scale it would be still more successful. In the disintegrating flour mill however, equally advantageous results appeared to be obtained with simpler and less expensive machinery.

Mr. E. A. Cowper enquired whether the Hungarian plan of steaming the grain beforehand was used in the disintegrating mill at Edinburgh, and also whether it was crushed by rollers before entering the disintegrator.

Mr. F. J. Bramwell said that at the Edinburgh mill the grain was steamed and was also slightly crushed by running between rollers before passing through the mill.

The President considered there were many points of great interest connected with the disintegrator, both as to its theoretical action, and as to its practical applications, which were very numerous and would no doubt become still more extensive. One remarkable feature of the machine was that while it completely pulverised the material it also mixed the particles in a most thorough manner; and this mixing action would be very valuable in many metallurgical processes. He hoped shortly to make an application of it in that way for mixing hard anthracite with bituminous small coal, for the purpose of making coke in South Wales. He had himself seen some of the disintegrators at work, and had been much struck by the efficiency of their action.

He proposed a vote of thanks to Mr. Carr for his paper, which was passed.

The following paper was then read:—

ON THE STRENGTH AND PROPORTIONS OF RIVETED JOINTS, WITH THE RESULTS OF SOME RECENT EXPERIMENTS.

By Mr. WALTER R. BROWNE, of Bristol.

The Strength of Riveted Joints is a question which has engaged the attention of several eminent engineers, and a considerable number of experiments have been made on the subject. Not having succeeded however in meeting with any thorough investigation on mathematical and practical principles combined, the writer has now attempted this in the present paper.

Taking first for consideration the simplest case of a single-riveted lap-joint with a single rivet only, as in Fig. 1, Plate 8, this joint may give way under a tensile strain in either of the following modes.

1st. The rivet may shear, as in Fig. 1; and in that case the breaking strain equals

shearing strength per square inch × sectional area of rivet.

2nd. Either plate may be crippled, that is crushed by the rivet forcing itself into the plate, as in Fig. 2. In this case the actual resistance offered by any portion A B of the circumference, Fig. 6, to the tensile strain, equals its resolved portion C D at right angles to the line of strain, multiplied by the thickness of the plate and by its crushing strength. Hence the whole resistance offered by the plate to crippling equals

crushing strength × thickness of plate × diameter E F of rivet.

3rd. The rivet may be torn out of the plate, as in Fig. 3, the plate breaking at the line K L. Then the part of the plate E M N F that is opposed to the rivet may be considered as a continuous

girder uniformly loaded, and the ultimate resistance consequently equals

$$\frac{\text{thickness of plate} \times (\text{depth K L})^2}{\text{length E F}} \times Q$$

the constant Q having to be determined by experiment, as the circumstances differ so much from those of ordinary girders.

4th. The plate may tear along the line G E F H, as in Fig. 4; and then the ultimate resistance equals

tensile strength per square inch × thickness of plate × (G E + F H)

5th. The rivet may force a piece of plate out before it, as in Fig. 5, the plate shearing along the lines E M and F N; and the ultimate resistance then equals

shearing strength per square inch × sectional area sheared.

This mode of fracture has been considered by one authority, Mr. Reed, as the normal manner in which a rivet forces its way out of a plate; but in the writer's opinion there is not any reason for believing such an action to occur, and the form of fracture in Fig. 5 could not take place before that in Fig. 3. It would be a similar occurrence to that of a uniformly loaded iron arch shearing at the two spandrils instead of breaking at the crown.

Omitting then this last case, the four modes of fracture to be considered are those shown in Figs. 1, 2, 3 and 4; and in a perfect joint the resistance in all these cases should be equal, and in all the greatest possible. Taking the expressions already given for these several resistances, it is seen that—

No. 1 depends only on the diameter of the rivet.

No. 2 depends on the diameter of the rivet, and the thickness of the plate.

No. 3 depends on both these, and the distance of the rivet from the end of the plate.

No. 4 depends on the thickness of the plate and the width on each side of the rivet.

Then by comparing Nos. 1 and 2 the proper proportion is obtained between the diameter of the rivet and the thickness of the plate; by comparing No. 1 with No. 3 the proper distance of the rivet from the end of the plate is obtained; and by comparing No. 1 with No. 4 the width of the plate is determined, or the pitch of the rivets where there are several.

Single-riveted Lap-joints.—First to compare the modes of fracture Nos. 1 and 2; let t be the thickness of the plates, and d the diameter of the rivet, the area of which will be $\cdot 7854\, d^2$; P the strain per square inch that will cripple the plate, and S the strain per square inch that will shear the rivet; then

$$S \times \cdot 7854\, d^2 = P \times t\, d$$

$$\text{or} \qquad \frac{d}{t} = \frac{P}{\cdot 7854\, S}$$

for the proportion of the diameter of rivet to the thickness of plate.

The values of P and S have now to be fixed; and in reference to P, the strain that will cripple the plate, the writer does not know of any direct experiments published on this point. If the ordinary values for the crushing and shearing strength of wrought iron are taken, the result obtained is that the diameter of rivet equals the thickness of plate very nearly, a proportion that is quite opposed to practice. This discrepancy arises from the circumstance that the experiments for values of crushing strength are made with cubes or short bars of the metal, which are free to move laterally in all directions; but in the present case on the contrary the metal that is being crushed is supported both by the surrounding part of the plate and also by the heads of the rivet, and is consequently much stronger.

One case in point is that of the fracture of suspension-bridge links, described by Sir Charles Fox,* which was apparently due to this cause; the holes became elongated, the bearing surface of the link against the pin was thickened, and after fracture the inside edges of the broken link could not be brought together again in consequence of their lateral enlargement. The values of P derived from these experiments are 40·0, 40·0, and 41·5 tons per square inch. Other values 38·1, 39·3, 40·6, and 41·4 have been obtained from data kindly furnished to the writer by Mr. George Berkley from similar experiments,† taking only those cases in which the fracture was clearly due to the crippling of the link.

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* Proceedings of the Royal Society, vol. xiv.; and Proceedings of the Institution of Civil Engineers, vol. xxx.

† Proceedings of the Institution of Civil Engineers, vol. xxx.

As however in both these sets of experiments a single pin with links of best bar iron was employed, it seemed very desirable for the present object to make some further experiments with actual boiler plate and rivets; and for this purpose a series of plates were prepared, and were tested for the writer at Mr. Kirkaldy's works; the whole preparation of the plates and also part of the expense was borne by Messrs. Fox Walker and Co. of the Atlas Iron Works, Bristol. In order to make sure that the joints should yield by this mode of fracture and no other, the rivets were made altogether out of proportion to the thickness of the plates, which was 5-16ths inch, while the rivets were 1 inch diameter; ample width was also given to the lap. The width of the joint in the line of the rivets was 13 inches, and three rivets were employed in all the cases. Half the specimens experimented upon were made with a lap joint, and the other half with a butt joint and two cover plates; the pitch of the rivets was 3 inches in the lap joints, and $3\frac{1}{2}$ inches in the butt joints. The results of these experiments are given in the appended Table I.

On the plates being tested by tension in Mr. Kirkaldy's machine, they all without exception tore through the rivet holes, as in Fig. 4. But the tensile strength per square inch of the area fractured was greatly below the strength of the plates, being only an average of 12·2 tons in the lap joints and 13·2 tons in the butt joints, as seen in Table I; and it follows therefore that the joints could not have yielded by fair tearing of the plates. The crippling action at the rivet holes, which is now being enquired into, would injure and weaken the metal, until either the rivets forced themselves out of the plate, or the plate itself tore through the holes. The latter happened first in these experiments; but there is no reasonable ground, the writer believes, for doubting that the ultimate cause of failure was the crippling of the metal in front of the rivets.

In order to test the reality of this crippling action, similar specimens of all the three qualities of iron that had been used, and of both kinds of joint, were subjected to a total tensile strain of 36 tons on the 13 inches width, and the rivet heads were afterwards planed off, so as to examine the dimensions of the holes. A slight

but unmistakable elongation was found to exist in the direction of the strain, amounting to about 1-20th inch; and taking into consideration that this is of the character of a "set," and also bearing in mind the way in which the metal is grasped by the rivet heads, and the support given by the surrounding plate, the amount of elongation appears quite sufficient to prove the existence of the crippling action. At the same time the ultimate tearing of the plates at the rivet holes serves to show why this crippling has attracted so little notice; and that, when not carried so far as to result in tearing, it may still exist as a dangerous and unsuspected source of weakness in joints otherwise excellent.

The mean value obtained from the experiments for the ultimate resistance to crippling of the plate, per square inch of the area of pressure in the rivet holes, is shown in Table I to be 39·5 tons for the lap joints, and 42·9 tons for the butt joints. These show a very close agreement with the results previously obtained from the experiments with suspension-bridge links, which averaged 39·8 and 40·5 tons per inch. The resistance to crippling appears therefore to be very different from and independent of the tensile strength of the iron; and as a general result, 40 tons per inch may be taken as the strain that will cripple the plate, or the value for P in the calculation.

Next to determine the value of S, or the strain per square inch that will shear the rivet. A considerable number of experiments have been made on this head, but their results do not agree very well together. In experiments made for the Britannia Bridge,* Mr. Clark found the shearing strength of rivets was only 20·4 tons per square inch for single shear. Only 18·82 tons for single shear has been given by Mr. Doyne as the average result of experiments; and as much as 26·50 has been given as an average by Mr. Maynard. The result of 22·70 tons was obtained by Mr. Reed† from experiments made at Chatham upon $\frac{3}{4}$ inch rivets

* The Britannia and Conway Tubular Bridges, vol. i., page 392.

† Treatise on Iron Shipbuilding, ch. xvii.

of Low Moor iron; 22·20 is the result of two experiments* with $\frac{3}{8}$ inch rivets by Sir William Fairbairn; and in eight experiments† by Mr. Henry Sharp upon steel plates jointed with iron rivets the result ranged from 16·76 to 20·78 and averaged 18·68 tons per square inch. The low value obtained in these last experiments is probably due to the circumstance that the steel plates, being harder, cut into the rivets sooner than iron plates would have done. Some similar explanation might possibly be found for the low result of 18·82 tons in Mr. Doyne's experiments; but on the other hand the result of 26·50 tons in Mr. Maynard's experiments seems exceptionally high. The result of 22·70 tons obtained in Mr. Reed's experiments, which were made with great care, is supported by the 22·20 tons of Sir William Fairbairn's experiments, and thus seems the most reliable; but as these experiments were made with the best quality of material, Low Moor iron, it will be safer for general purposes to take 22 tons per inch as the shearing strength of the rivets, or the value of S for single shear.

Taking this value, and the 40 tons per inch previously ascertained as the value of P or the crippling strength, the expression for the proportion of the diameter of rivet to the thickness of plate

$$\frac{d}{t} = \frac{P}{.7854\,S} \quad \text{becomes} \quad \frac{d}{t} = 2{\cdot}31$$

giving the result diameter equals 2·31 times thickness. It thus appears that the ordinary rule of making the diameter of rivet double the thickness of plate is nearly correct, giving however some advantage to the plate. This proportion of 2 to 1 will therefore be retained in the investigation of the other points in question; and the diameter of the rivet will be taken throughout as the basis of comparison, whereby a sufficient thickness of plate will be ensured.

* Useful Information for Engineers, 1st series, appendix I., part 2, experiments 30 and 42.

3 rivets, $\frac{3}{8}$ inch diam., sheared with 16,603 lbs., whence $S = 22{\cdot}37$ tons per inch.
3 ,, $\frac{3}{8}$,, ,, 16,351 ,, ,, $S = 22{\cdot}03$,, ,,

† Transactions of the Institution of Naval Architects, 1868. The details were kindly supplied by Mr. Sharp to the author.

The next step is to equalise the strength of the joint in the first and third modes of fracture, or to determine the distance of the rivet from the edge, or the lap of the plate, which will give the same resistance to tearing the rivet out of the plate as to shearing the rivet in the hole. Putting a for the distance required, K L, Fig. 6, the equation becomes

$$S \times \cdot 7854\, d^2 = Q \times \frac{t a^2}{d}$$

the value of Q having to be determined by experiment.

Three experiments of Sir William Fairbairn, in which the rivets are said to have torn out of the holes, are the only ones the writer has met with bearing on this point*; and these give the values of 32·6, 37·9, and 44·0, or an average of 38·2 tons for Q. Taking $Q = 38$, and the other values as before, namely $S = 22$ and $d = 2\,t$, the result is that

$$\frac{a}{d} = 0{\cdot}95$$

or the proportion of the distance of rivet from end of plate to the diameter of the rivet itself should be 0·95. Thus the ordinary rule of having a space equal to one diameter between the rivet hole and the end of the plate proves to be substantially correct, when the diameter of rivet is double the thickness of plate; and the lap of the joint then becomes three times the diameter of rivet.

When however the diameter of rivet is less in proportion, as must be the case with thick plates, the result is different, and if the diameter is only $1\frac{1}{2}$ times the thickness, or $d = 1\frac{1}{2}\,t$, then

$$\frac{a}{d} = 0{\cdot}82$$

or the distance from end of plate is reduced to a proportion of 0·82 or 4-5ths diameter of rivet.

Lastly the strength of the joint has to be equalised in the first and fourth modes of fracture, so that the width of plate on each side of the rivet hole shall offer the same resistance to tearing the plate as the rivet does to shearing. Putting b for the width required on each side of the hole, the equation becomes

$$S \times \cdot 7854\, d^2 = R \times 2\, b\, t$$

* Useful Information for Engineers, experiments 25, 22, and 23.

where the value of R or the strength to resist tearing has still to be determined; for which purpose the following data are available.

In the experiments by Mr. Reed before referred to this value is

18 tons per inch for punched plate
22 ,, ,, unpunched ,,

In the experiments* of Sir William Fairbairn with single-riveted lap-joints this value averages

19·9 tons per inch for the riveted plates,
and 25·0 tons per inch is stated for the unpunched plates.

In other experiments with double-riveted and butt joints higher values were obtained. The results of a series of experiments on double-riveted and butt-jointed plates, made by Mr. Brunel, and communicated to the writer by Mr. Howard, Engineer to the Bristol Docks, bear fairly upon the present point, and give a mean value of

18·25 tons per inch for the riveted plates, mean of 6 experiments
20·60 ,, ,, unpunched ,, ,, 5 ,,

These values are considerably lower than those in Sir William Fairbairn's experiments, although obtained from double-riveted and butt-jointed plates; and this probably arises from the iron in the latter experiments being of better quality, possessing the unusually high tensile strength of 25 tons per inch; the plates were also thin in that case, being less than $\frac{1}{4}$ inch thick, which would render them proportionately somewhat stronger. Hence for general purposes it seems safer to take 18 tons per inch as the tearing strength of the plate at the rivet holes, or the value of R, as this value is confirmed by Mr. Reed's experiments. Taking then 18 tons for the value of R, and $S = 22$ tons as before, in the equation

$$S \times \cdot 7854\, d^2 = R \times 2\, b\, t$$

the result obtained is

$$b = 0{\cdot}48 \times \frac{d}{t} \times d.$$

And if the diameter of rivet is taken at twice the thickness of plate, as before, or $d = 2\, t$, then

$$b = 0{\cdot}96\, d = d \text{ very nearly,}$$

and the result is that the width on each side of the rivet-hole should be equal to the diameter of rivet in the case of a single rivet, so that

* Useful Information for Engineers, experiments 21, 27, 28, 29, and 33.

in a row of rivets the space between them should be equal to twice the diameter of a rivet, or as a practical rule the pitch should be equal to three diameters.

With thick plates, where the diameter of the rivets is less than twice the thickness of plate, the pitch will be less; and if m be taken as the ratio of diameter to thickness, then

$$b = \frac{m}{2} \times d$$

or the space between the rivet holes will be m times the diameter of rivet.

If the plates are drilled instead of punched, the strength of the portion between the rivet holes will not be reduced below the general tensile strength of the plate, which may be taken at 22 tons per inch from Mr. Reed's experiments already referred to*; and substituting this value for R,

$$b = 0{\cdot}39 \times \frac{d}{t} \times d,$$

and if $d = 2\,t$, then

$$b = 0{\cdot}78\,d$$

or the proportion of the space between the rivet holes becomes 1·56 times the diameter, and the pitch equal to $2\frac{3}{5}$ diameters.

With regard to the proportionate strength of the plate at the joint compared with that of the entire plate, the sectional area of the plate is reduced to two-thirds at the line of rivets, when the pitch is 3 diameters; and the strength of the metal between the rivet holes is further reduced in punched plates from 22 to 18 tons per inch, making the total strength at the joint $\frac{2}{3} \times \frac{18}{22}$ or 55 per cent. of that of the entire plate, with punched holes. With drilled holes having the pitch of $2\frac{3}{5}$ diameters, the tensile strength of the metal not being reduced by punching, the proportionate strength is in the ratio of $1\frac{3}{5}$ to $2\frac{3}{5}$, and is therefore 62 per cent.

The rules thus obtained for the proportions of single-riveted lap-joints are accordingly as follows, as shown in Figs. 7 and 8, Plate 9:—

Diameter of rivet	=	2 times thickness of plate
Lap	=	3 diameters
Pitch	=	3 diameters

* Also from Mr. Kirkaldy's Experiments on Wrought-Iron and Steel, page 96.

Taking however a $1\frac{1}{8}$ inch rivet as the largest that can be worked in practice, this rule of the diameter equal to twice the thickness cannot be followed for plates thicker than 9-16ths inch; but such plates are seldom used except in marine boilers, where they are always double-riveted. The above rules agree closely with Sir William Fairbairn's table in extensive use, except that for $\frac{1}{2}$ inch plates and upwards the diameter of rivet is there made $1\frac{1}{2}$ times the thickness. Other rules that are in use appear somewhat inconsistent and arbitrary; for in the case of a 9-16ths inch plate the diameter of rivet is $\frac{3}{4}$ inch by the Millwall and Lloyd's rule, $\frac{13}{16}$ inch by the Liverpool rule, and $\frac{7}{8}$ inch by that of H. M. Dockyards.

Double-riveted Lap-joints.—The case of double-riveted joints has now to be considered; and here the first point, namely the proportion of diameter of rivet to thickness of plate, remains the same as in single-riveted joints, the rivets being under the same circumstances of strain in both cases.

The second point is the lap of the joint; for which the distance between the two rows of rivets has to be determined. The only experiments known to the writer that bear upon this are those of Mr. Brunel previously referred to. In these the line of fracture in several cases was a zigzag, running backwards and forwards between the two rows of rivets, as in Figs. 9 and 10, Plate 9; and this shows that the rows were too near together in those cases. As the effect of punching is to weaken the plate to some distance all round the punched hole, the result will be that in the space between any two successive holes in the straight line of rivets the plate is weakened twice the distance that the punching affects, but in the zigzag line between the same two holes the plate is weakened to the extent of four times the same distance. Hence though the zigzag line will always be the longer in itself, it may be really weaker than the straight line, if the two rows are near together. The proportion of the distance between the pitch lines to the pitch itself was respectively from 40 per cent. in Fig. 9 to 62 per cent. in Fig. 10, in the experiments in which the fracture took the zigzag line; but in another experiment, Fig. 11, in which the proportion was as great

as 67 per cent., the fracture took place in the straight line. It therefore seems safe to make the distance between the pitch lines 67 per cent. or 2-3rds of the pitch in zigzag riveting.

In chain-riveting however, the rivets in the second row being opposite those in the first row, as in Fig. 12, are in the same position with respect to the first row as the rivets in a single-riveted joint to the edge of the lap. Hence by the same rule as before, the distance between the rivet holes in the two rows will be one diameter, making the distance between the pitch lines 2 diameters; but as the plate between the holes will be injured at both sides by punching, it will be safer to make the distance $2\frac{1}{2}$ diameters between the pitch lines. This gives the total lap $5\frac{1}{2}$ diameters in chain-riveted joints, which agrees with the rules in use at Lloyd's.

To find the pitch for double-riveted joints, the expression will be the same as before for single-riveted joints, except that there are double the number of rivets to be sheared; and the equation will therefore be

$$2\,(S \times \cdot 7854\, d^2) = R \times 2\, b\, t.$$

In determining the value of R in this case, or the strength to resist tearing between the rivet holes, it has to be observed that, as the rivets are much further apart than in single-riveting, the injury done by punching will be proportionately not so great; and it was found in Mr. Brunel's experiments with double-riveted joints that plates having a tensile strength of 20·6 tons gave a mean value of 18·2 tons for the resistance to tearing between the rivet holes. Hence with the tensile strength of 22 tons that has been taken in the previous calculations the proportionate value for R will be $22 \times \frac{18\cdot 2}{20\cdot 6}$ or $19\frac{1}{2}$ tons for tearing. Adopting this value, and taking $S = 22$ as before, the equation becomes

$$b = 0\cdot 89 \times \frac{d}{t} \times d$$

and if $d = 2\,t$, then

$$b = 1\cdot 78\, d.$$

The result obtained is therefore that the pitch is to be 4·56 diameters, or say $4\frac{1}{2}$ diameters in double-riveted joints. The distance between the pitch lines in zigzag riveting having already been shown to be 2-3rds of the pitch will therefore amount to 3 diameters, making the total lap in that case 6 diameters.

The rules thus obtained for double-riveted lap-joints with punched holes are accordingly, as shown in Figs. 12 and 13, Plate 9:—

Diameter of rivet	$= 2$ times thickness of plate
Pitch	$= 4\frac{1}{2}$ diameters
Lap	$\begin{cases} = 5\frac{1}{2} \text{ diameters in chain riveting} \\ = 6 \text{ diameters in zigzag riveting} \end{cases}$

The proportionate strength of the joint as compared with that of the entire plate is $\frac{19 \cdot 5}{22 \cdot 0} \times \frac{3 \cdot 5}{4 \cdot 5} = 69$ per cent. with punched holes.

If the holes are drilled instead of punched, the full tensile strength 22 tons has to be taken instead of $19\frac{1}{2}$ tons for the tearing strength between the rivet holes, or the value of R in the equation; and the result then obtained for the pitch is 4 diameters, instead of $4\frac{1}{2}$ diameters with punched holes. The lap in zigzag riveting becomes consequently reduced with the drilled holes to $5\frac{1}{2}$ instead of 6 diameters, and to 5 instead of $5\frac{1}{2}$ diameters in chain riveting; and the proportionate strength of the joint then amounts to 75 per cent. of that of the entire plate.

In considering the case of thick plates, as in marine boilers, where the diameter of the rivets cannot be made twice the thickness of the plate, the proportion of $1\frac{1}{2}$ times may first be taken; and substituting this value $d = 1\frac{1}{2}\, t$ in place of $d = 2\, t$ in the previous calculations, the results are

In punched plates, Pitch $= 3\frac{2}{3}$ diam., Strength $\frac{19 \cdot 5}{22 \cdot 0} \times \frac{2 \cdot 66}{3 \cdot 66} = 64$ per cent.

In drilled plates, Pitch $= 3\frac{1}{3}$ diam., Strength $\frac{2 \cdot 33}{3 \cdot 33} = 70$ per cent.

Taking next the diameter of rivet equal to the thickness of plate, the corresponding results are

In punched plates, Pitch $= 2\frac{3}{4}$ diam., Strength $\frac{19 \cdot 5}{22 \cdot 0} \times \frac{1 \cdot 75}{2 \cdot 75} = 56$ per cent.

In drilled plates, Pitch $= 2\frac{1}{2}$ diam., Strength $\frac{1 \cdot 50}{2 \cdot 50} = 60$ per cent.

Single-riveted Butt-joints.—The next portion of the subject to be investigated is the proportions of Butt joints, in which the two plates are connected by means of cover-strips riveted to each plate; and these covers are either on one side only, as in Figs. 14 and 15, or on both sides, as in Figs. 16 and 17, Plate 10.

In the case of a single cover, each half of the joint is in effect simply a lap-joint, the cover representing a separate plate; consequently the proportions previously obtained apply in this case, as shown in Figs. 14 and 15, whether the joint be single-riveted or double-riveted. It follows also that the thickness of the cover should be the same as that of the plates.

Next with double covers, as in Figs. 16 and 17, the thickness required for each of the two cover strips is only half that of the plates, as they must both of them tear if the joint gives way. In this case there is the peculiarity that if the joint gives way by the failure of the rivets, it must do so from their shearing in two places instead of one; and as double the area has then to be sheared, the equation previously employed becomes

$$2\,S \times \cdot 7854\, d^2 = P \times t\,d$$

or the proportion of diameter of rivet to thickness of plate is

$$\frac{d}{t} = \frac{P}{1\cdot 57\, S}$$

In this expression the values have to be ascertained from experiment for P the resistance of the plate to crippling, and S the shearing strength of the rivets, both in tons per square inch. From the experiments made by the writer on the resistance to crippling in butt joints this amounts to a mean of 42·9 tons, as shown in Table I appended, or say 43 tons per square inch for the value of P.

In reference to the value of S, the experiments on record upon the resistance of rivets to double shear present considerable discrepancies, as in the case of those previously referred to upon the resistance to single shear; and the results range from 16·8 to 22·3 tons per square inch. The several values in the experiments are

Mr. H. Sharp	18·68	tons for Single shear	16·80	tons for Double shear
Mr. Doyne	18·82	,,	17·55	,,
Mr. Maynard	26·50	,,	19·60	,,
Mr. Reed	22·70	,,	20·37	,,
Mr. Brunel	...		21·00	,,
Mr. Clark	20·40	,,	22·30*	,,

* This is apparently the result of a single experiment only, and is no doubt unduly high.

In Mr. Sharp's experiments there is one case bearing on the present question which gives the above value of 16·8 for S, but for the reason named before this is probably too low. Mr. Reed's result of 20·37 is obtained from the shearing strain of a $\frac{3}{4}$ inch rivet in double shear. As the experiments by Mr. Brunel were made with plates $\frac{3}{8}$ and $\frac{1}{2}$ inch thick and 20 inches wide, admitting five rivets in a row, considerable confidence may be placed in their results; and in two of these, bearing directly on the present question, in which seven and ten rivets respectively were sheared, the results were 21·1 and 20·9, averaging 21 tons per inch. In two other experiments, in which the plates tore between the rivet holes, the ultimate strain on the rivets gave a value above 22 tons for S. On the whole the best value to be taken appears to be 21 tons per square inch for the shearing strength of the rivet in double shear, in place of the 22 tons per inch previously determined for the case of single shear.

Taking then the values $S = 21$ and $P = 43$, the result obtained is

$$\frac{d}{t} = 1{\cdot}30$$

or say $1\frac{1}{4}$ times for the proportion of the diameter of rivet to the thickness of plate, giving a slight advantage to the plate.

In the next place, to find the distance of rivet from edge of plate, the equation will be the same as before for a lap joint, except that the resistance to shearing has to be doubled; the equation therefore becomes

$$2\,S \times {\cdot}7854\,d^2 = Q \times \frac{t\,a^2}{d}$$

The value of Q will be the same as before, namely 38; also $S = 21$, and $d = 1\frac{1}{4}\,t$; the result obtained is consequently

$$\frac{a}{d} = 1{\cdot}04$$

or the distance of rivet from edge of plate is practically equal to the diameter, the same as in the case of lap joints. This proportion applies both to the plates and the cover strips, and holds substantially even if the ratio of diameter to thickness be somewhat less than $1\frac{1}{4}$ times. The amount of the lap for the cover strips will therefore be 3 diameters on each plate, making the width of the cover strips equal to 6 diameters.

Then to find the pitch; as the plate may tear across the rivet holes just as before, the equation will be the same, except that the resistance to shearing has to be doubled; and the equation becomes

$$2\,S \times \cdot 7854\, d^2 = R \times 2\, b\, t.$$

The value previously taken for the tearing strength R, namely 18 tons per inch, agrees with Mr. Brunel's experiments, in all of which the joints were of this description; and it may therefore be safely taken for the present case. Then taking the other values the same as before, namely $S = 21$, and $d = 1\frac{1}{4}\,t$, the result obtained is

$$b = 1{\cdot}15\, d$$

or the pitch is equal to $3\frac{1}{4}$ diameters.

The rules thus obtained for the proportions of single-riveted butt-joints with double covers and punched holes are therefore, as shown in Figs. 16 and 17, Plate 10:—

Diameter of rivets	= $1\frac{1}{4}$ times thickness of plate
Pitch	= $3\frac{1}{4}$ diameters
Width of cover strips	= 6 diameters

The proportionate strength of the joint, as compared with that of the entire plate, is $\frac{18}{22} \times \frac{2{\cdot}25}{3{\cdot}25}$ or 57 per cent. with punched plates.

For drilled plates the tearing strength has to be taken at the full tensile value of 22 tons instead of 18; and then

$$b = 0{\cdot}94\, d.$$

The result thus obtained is pitch = 3 diameters; and the corresponding proportionate strength is $\frac{2}{3}$ or 67 per cent. of that of the entire plate.

Double-riveted Butt-joints.—The last form of joint to be considered is that of a butt joint with two cover strips, each double-riveted, as in Figs. 18, 19, and 20, Plate 10. The thickness of the cover strips will as before be half the thickness of the plates.

In this case the proportion of diameter of rivet to thickness of plate is the same as in the previous single-riveted joint, or $1\frac{1}{4}$ times the thickness, the rivets being under the same circumstances of strain in both cases.

Then to find the distance between the two rows of rivets and the distance of the outer row from the edge of the plate, the conclusions previously arrived at for double-riveted lap-joints apply

fully to the present case, as the experiments by Mr. Brunel upon which they are chiefly founded were made with double-riveted butt-joints. Consequently the width of the cover strips is double the lap previously ascertained, or 11 diameters in chain riveting, as in Fig. 19.

Last to find the pitch, the calculation is the same as for single-riveted joints, except that double the number of rivets have to be sheared; and the equation consequently becomes

$$2\ (2\ S \times \cdot 7854\ d^2) = R \times 2\ b\ t$$

and taking $R = 19\frac{1}{2}$, as with double-riveted lap-joints, and $S = 21$, the result is $b = 1{\cdot}69 \times \frac{d}{t} \times d$; and if $d = 1\frac{1}{4}\ t$, then

$$b = 2{\cdot}11\ d$$

thus making the pitch equal to $5\frac{1}{4}$ diameters. The distance between the pitch lines in zigzag riveting being as before 2-3rds of the pitch, the width of the cover strips becomes 13 diameters in zigzag riveting, as in Fig. 20.

The rules for double-riveted butt-joints with double cover-strips and punched holes are therefore, as shown in Figs. 18, 19, and 20, Plate 10:—

Diameter of rivet	=	$1\frac{1}{4}$ times thickness of plate
Pitch	=	$5\frac{1}{4}$ diameters
Width of cover strips	=	11 diameters in chain riveting
	=	13 diameters in zigzag riveting

The proportionate strength of the joint is $\frac{19{\cdot}5}{22{\cdot}0} \times \frac{4{\cdot}25}{5{\cdot}25}$ or 72 per cent. of that of the entire plate, with punched holes.

For drilled holes, making the same correction as before, by putting the full value of 22 tons for R the tearing strength, instead of only $19\frac{1}{2}$ tons, the equation becomes

$$b = 1{\cdot}87\ d$$

whence the pitch is equal to $4\frac{3}{4}$ diameters, and the proportionate strength of joint is $\frac{3{\cdot}75}{4{\cdot}75}$ or 79 per cent. of that of the entire plate.

Conclusions.—The results of the foregoing investigation into the proportions for the different descriptions of joints are shown in Table II appended; and are now offered for consideration, not as any final conclusion upon the subject, but simply as a fair deduction

from the materials at present available. There are however many points on which information is meagre, and many on which it is wanting altogether; and the writer would feel great pleasure in seeing a revision of these results, by means of some thorough course of experiments on a sufficiently large scale. It has to be observed that all the experiments upon which the results have been based were made with actual rivets and riveted work; so that all incidental considerations, such as alteration in the iron by the process of riveting, or friction of the rivet heads, are virtually included in the results.

One conclusion that appears to arise from the present investigation is that the advantage as regards strength in butt joints, even with double cover-strips, is very slight over lap joints, the proportionate strength of the joint to the entire plate being increased only from 69 to 72 per cent. in double-riveted punched plates. The reason for this appears in the tendency to crippling that is shown in the writer's experiments, in relation to which the plate is virtually as weak in the case of the butt joints as in the lap joints. If this view be correct, it would seem that a useless expense is incurred in employing butt joints for boiler work, so far as strength of joint is concerned.

Another conclusion from the investigation appears to be that, in double-riveting, chain is preferable to zigzag riveting, being equally strong and requiring a smaller width of lap or cover strip; and this plan was also the one recommended by Lloyd's Committee.

Lastly a circumstance that especially attracts attention is the proportionate weakness of all the descriptions of joint as compared with the strength of the plates. In the best instance the strength of the joint is less than four-fifths of that of the plate, so that 20 per cent. of the whole iron in a boiler is wasted so far as strength is concerned; even this result is only obtained by the expensive process of using two cover strips and drilling all the rivet holes. In a common single-riveted lap-joint with punched holes the proportion of strength is only 55 per cent., or little more than half that of the plates. This serious waste of material requires consideration as to the means of reducing the amount.

In considering the strains on a boiler from internal pressure, it has to be borne in mind that in all cylindrical boilers the strain upon the transverse joints is only one half of that upon the longitudinal joints. The strain per inch run on the longitudinal joints is proportional to the radius of the boiler, while that on the transverse joints is proportional to the area of the transverse circle of the boiler divided by the circumference of the same circle, which amounts to half the radius, instead of the whole radius as in the other case of the longitudinal joint; and the strain on the transverse joints is consequently only one half of that on the longitudinal joints, per inch run of each. This circumstance does not appear to have received the attention it requires, as boilers are generally made with the same description of joint in both directions; and thus the very unsatisfactory condition arises that, although the plates in boilers are subjected to a strain on their longitudinal edges double of that which is acting upon their transverse edges, yet they are united together by the same strength of joint at each edge, this joint having an effective strength little greater than half that of the plates.

Two modes are known to the writer for remedying this inequality in the strength of the joints. One of these is the Diagonal-jointed boiler of Messrs. Wright, shown in Fig. 21, Plate 11, in which the lines of joint, instead of running transversely and longitudinally, are ranged diagonally across the boiler. Taking the angle of the joints at 45°, and considering any square portion of the boiler surface of which the joint forms a diagonal, it will be seen that instead of the two pairs of equal and opposite tensions, one pair double in amount of the other pair, which would act on the sides of the square in ordinary square jointing, there are with the diagonal jointing two equal and opposite resultant tensions acting across the diagonal joint. The resultant tension per inch run of the joint is found on calculation to be about four fifths of the greater tension, and it acts not exactly at right angles to the joint, but at an angle of about 72° with it. The latter circumstance however does not materially affect the result, and the tension on the diagonal joint may therefore be taken at four fifths of that on a longitudinal joint; consequently the effective strength of the joint and of the boiler is increased in the ratio of

four to five. Thus in a punched lap-joint, if single-riveted, the proportionate strength of joint as compared with that of the entire plate is increased from 55 to 69 per cent., and if double-riveted from 69 to 86 per cent. The diagonal joints have in most cases to be replaced by transverse seams at the ends of the boiler; but as the tension on a transverse joint is only one half of that on a longitudinal one, this does not form any objection. The writer is not aware whether any practical difficulties as regards workmanship and expense attend this diagonal construction of boiler; but so far as strength goes, it certainly seems to possess advantages that should not be overlooked.

The other mode of remedying the inequality in the strength of the transverse and longitudinal joints, is by the use of plates thickened along two opposite edges, as shown in Figs. 22 and 23, Plate 11; such plates may be rolled without any great practical difficulty, and are in fact rolled at the Low Moor Works and elsewhere, the thickening being produced along the two sides of the plate. Taking the case of plates $\frac{3}{8}$ inch thick, and rolled with edges thickened to $\frac{1}{2}$ inch: when these thickened edges are placed lengthwise in the boiler and double-riveted, the proportion of strength for the longitudinal joints compared with the body of the plate will be $1\frac{1}{3} \times 69 = 92$ per cent. For the transverse joints, as the tension is only half as great, a single-riveted lap-joint with a proportion of strength of 55 per cent. will be quite sufficient. There does not seem anything objectionable in such a construction of boiler, the only inconvenience being where the thickened edge of a plate passes under the adjoining plate at a transverse joint, which would require the corner to be drawn down for the purpose. This plan admits of making any boiler of equal strength throughout, without the necessity either of butt-jointing or of drilling the rivet holes. An advantage attending the use of thickened-edge plates is in reference to the ordinary corrosion at or near the joints, which is so fruitful a source of boiler explosions. The depth of this corrosion does not depend upon the thickness of the plates, and would be no more for a $\frac{1}{2}$ inch than for a $\frac{3}{8}$ inch plate; but it might produce an explosion with the latter, where the former would continue safe.

TABLE I.

EXPERIMENTS ON RIVETED JOINTS.

Lap Joints, Single-riveted.

Plates.		Total Breaking Strain.	RESISTANCE.			
			Tension.		Crippling.	
Brand.	Size. Ins.	Tons.	Tons p. sq. in.	Mean.	Tons p. sq. in.	Mean.
K B C	13·20 × ·32	33·20	10·26		33·57	
do	13·10 × ·31	36·93	11·90	11·74	38·55	37·93
do	13·00 × ·32	40·14	12·66		40·59	
do	13·00 × ·32	38·56	12·16		38·99	
BW Best	13·10 × ·32	39·00	12·18		39·44	
do	13·00 × ·31	37·00	12·04	12·06	38·63	38·82
do	13·00 × ·31	36·76	11·97		38·38	
B B H	13·10 × ·31	40·08	12·92		41·85	
do	13·10 × ·30	39·09	13·02	12·95	42·17	41·81
do	13·00 × ·30	38·37	12·91		41·40	
Mean				12·25		39·52

Butt Joints, with two covers, Single-riveted.

Plates.		Total Breaking Strain.	RESISTANCE.			
			Tension.		Crippling.	
Brand.	Size. Ins.	Tons.	Tons p. sq. in.	Mean.	Tons p. sq. in.	Mean.
K B C	13·10 × ·32	41·20	12·86		41·67	
do	13·10 × ·33	43·58	13·19	12·97	42·73	42·07
do	13·15 × ·31	40·06	12·85		41·82	
BW Best	13·10 × ·30	38·01	12·66		41·01	
do	13·10 × ·32	42·13	13·15	12·83	42·61	41·44
do	13·00 × ·31	38·98	12·69		40·70	
B B H	13·00 × ·30	39·81	13·39		42·94	
do	13·10 × ·32	45·78	14·29	13·98	46·30	45·16
do	13·12 × ·31	44·30	14·25		46·25	
Mean				13·26		42·89

All the experiments were made with plates joined by three rivets of 1·03 inch diameter, 3 ins. pitch in the lap joints, and 3½ ins. pitch in the butt joints.

TABLE II

Rules for Proportions of Riveted Joints.

Description of Joint.	Riveting	Rivet Holes.	PROPORTIONS: Diameter to Thickness.	Lap or Cover to Diameter.	Pitch to Diameter	Per Cent Strength of Joint to Plate
				Lap.		
Lap	Single	Punched	2	3	3	55
		Drilled	2	3	$2\frac{2}{3}$	62
				Chain Zig		
Lap	Double	Punched	2	$5\frac{1}{2}$ 6	$4\frac{1}{2}$	69
		Drilled	2	5 $5\frac{1}{2}$	4	75
				Cover.		
Butt, 1 cover	Single	Punched	2	6	3	55
		Drilled	2	6	$2\frac{2}{3}$	62
Butt, 1 cover	Double	Punched	2	11 12	$4\frac{1}{2}$	69
		Drilled	2	10 11	4	75
Butt, 2 covers	Single	Punched	$1\frac{1}{4}$	6	$3\frac{1}{4}$	57
		Drilled	$1\frac{1}{4}$	6	3	67
Butt, 2 covers	Double	Punched	$1\frac{1}{4}$	11 13	$5\frac{1}{4}$	72
		Drilled	$1\frac{1}{4}$	10 12	$4\frac{3}{4}$	79

TABLE III.

Mean Experimental Values for Constants.

P Crippling strain		lap joints .	40	tons p. sq. in.
		butt joints .	43	..
S Shearing rivets		single shear	22	..
		double shear	21	..
Q Tearing rivets out of holes			38	..
R Tearing strength of plate between rivet holes	single-riveting	punched holes	18	..
		drilled holes	22	..
	double-riveting	punched holes	$19\frac{1}{2}$	..
		drilled holes	22	..

In conclusion the writer would express a hope, in submitting these results to the Institution, that they may not be considered superfluous or out of place, on the ground that practical experience affords the means of designing riveted joints sufficiently well, without having recourse to theory. For on the contrary, cases have occurred of joints designed in that way which have shown on testing a proportion of strength considerably under 50 per cent. of that of the body of the plate, although supposed to be based on sound practical principles; and the serious consequences arising from defective construction of joints, in the explosion of boilers or leakage of ships, show the importance of the most complete investigation of the subject.

The PRESIDENT moved that the discussion of the paper just read be adjourned to the following meeting, which was passed.

The Meeting then terminated. In the evening a number of the members dined together in celebration of the Twenty-fifth Anniversary of the Institution.

Experiments on Strength of Diagonal and Straight Joints

Fig. 24. *Diagonal Joint*

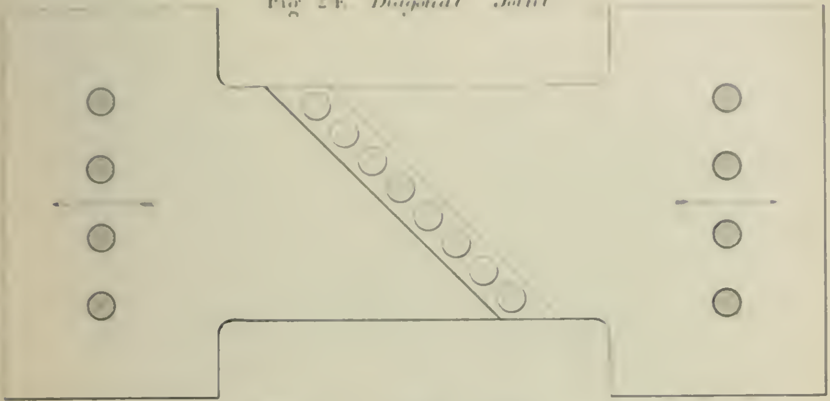


Fig. 25. *Straight Joint.*

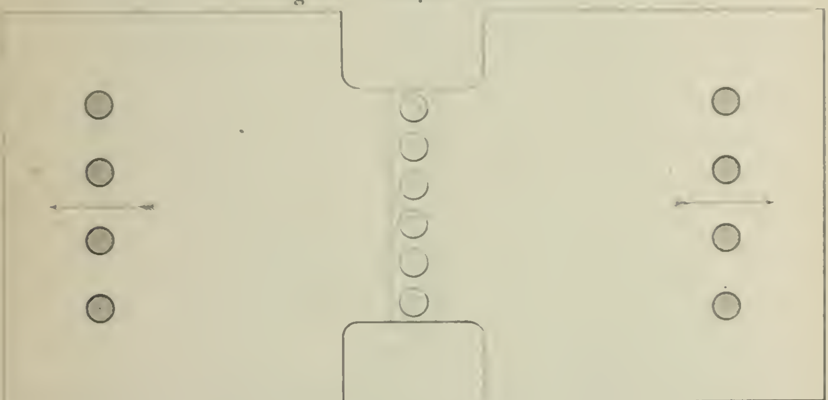
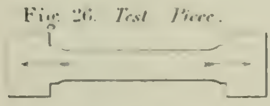


Fig. 26. *Test Piece.*



Experiments on Strength of Drilled and Punched Bars and Plates.

Fig. 27. *Bar Iron.*

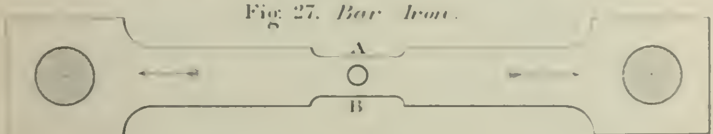
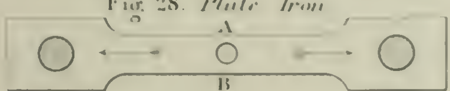


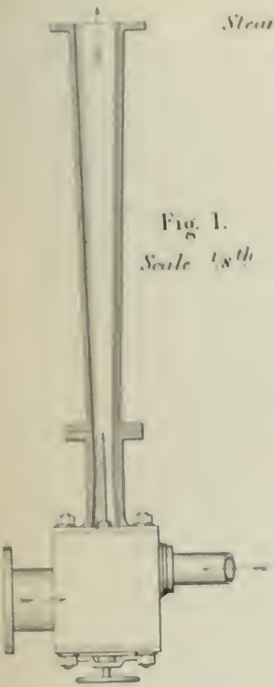
Fig. 28. *Plate Iron*

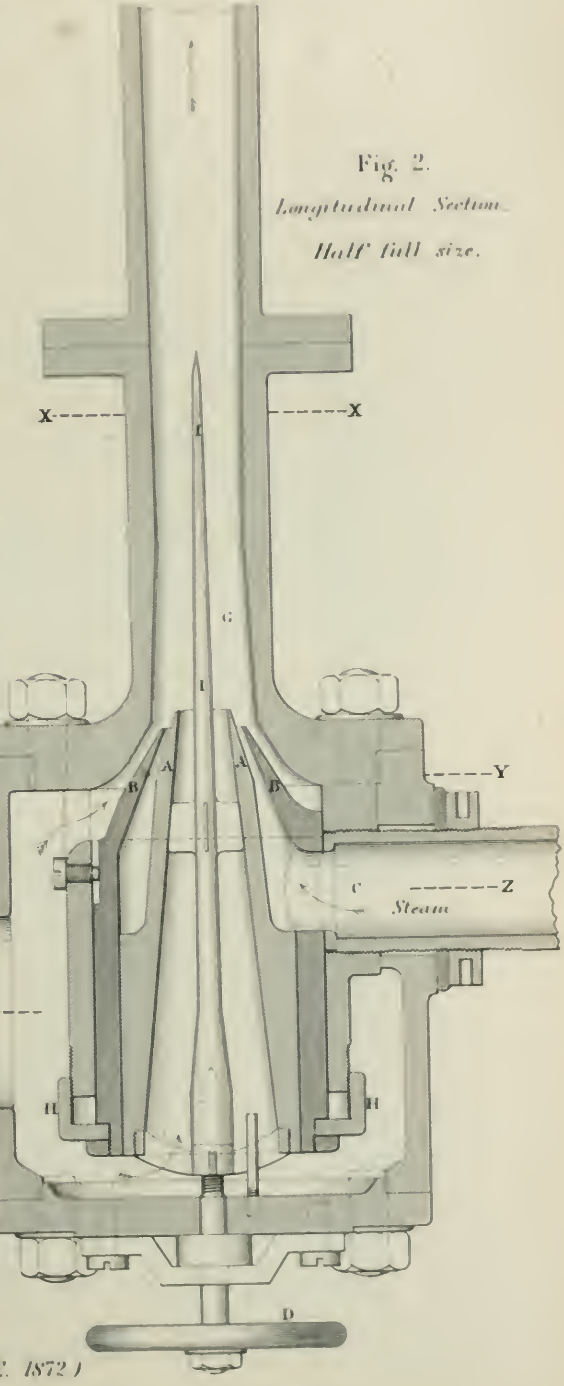


Scale 1/10th

STEAM JET.

Steam-Jet Exhauster or Blower





Steam-Jet Exhauster or Blower.

Fig. 3. *Transverse Section at* XX.

Fig. 4 *Transverse Section at* YY.

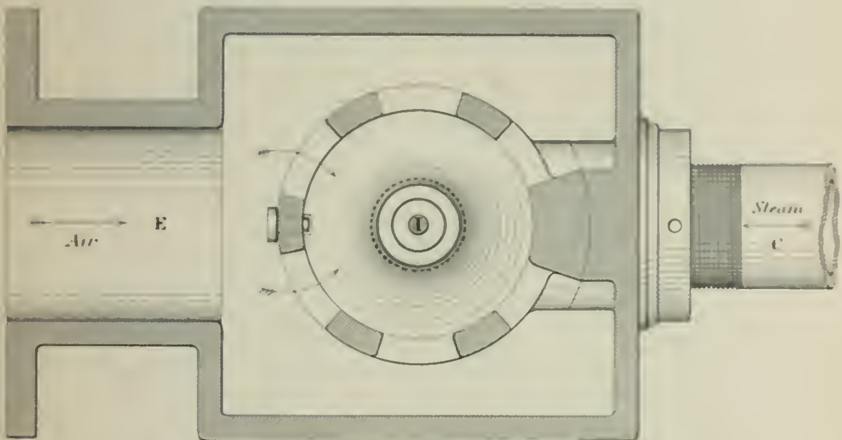
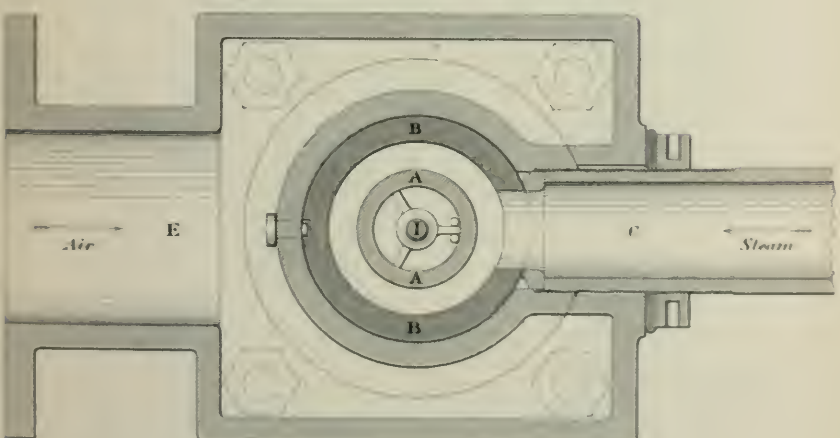


Fig. 5. *Transverse Section at* Z Z.



 Half full size.

STEAM JET.

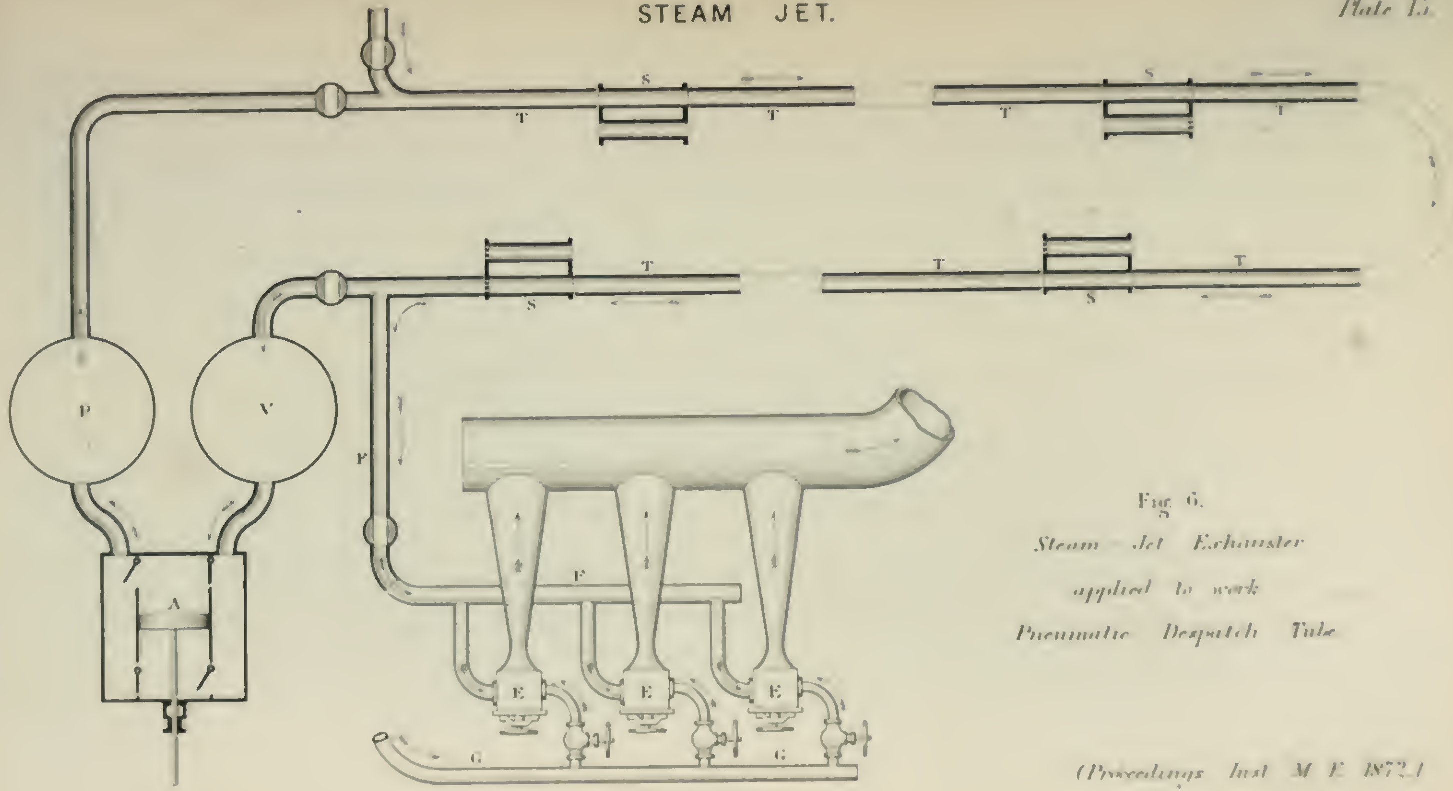


Fig. 6.

Steam Jet Exhauster applied to work Pneumatic Despatch Tube

(Proceedings Inst. M. E. 1872.)

STEAM JET.

Pneumatic Despatch Tube.

Piston Carrier travelling through tube.

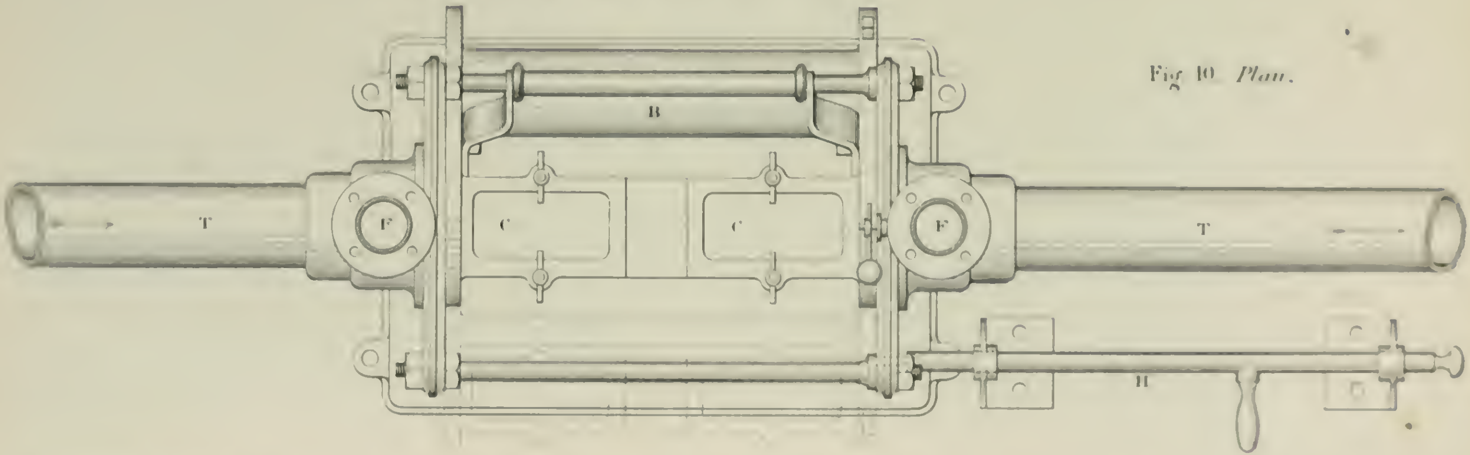
Fig. 7. *Side Elevation.*

Fig. 8. *Transverse Section.*

Fig. 9. *Longitudinal Section.*

Intercepting Apparatus at Stations.

Fig. 10. *Plan.*



Scale 1/8th

0 5 10 15 20 25 30 Inches

STEAM JET.

Pneumatic Despatch Tube.

Intercepting Apparatus at Stations.

Fig. 11. *Transverse Section.*

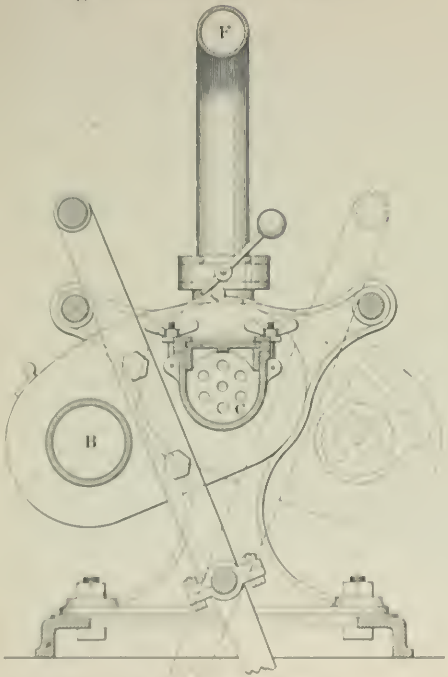
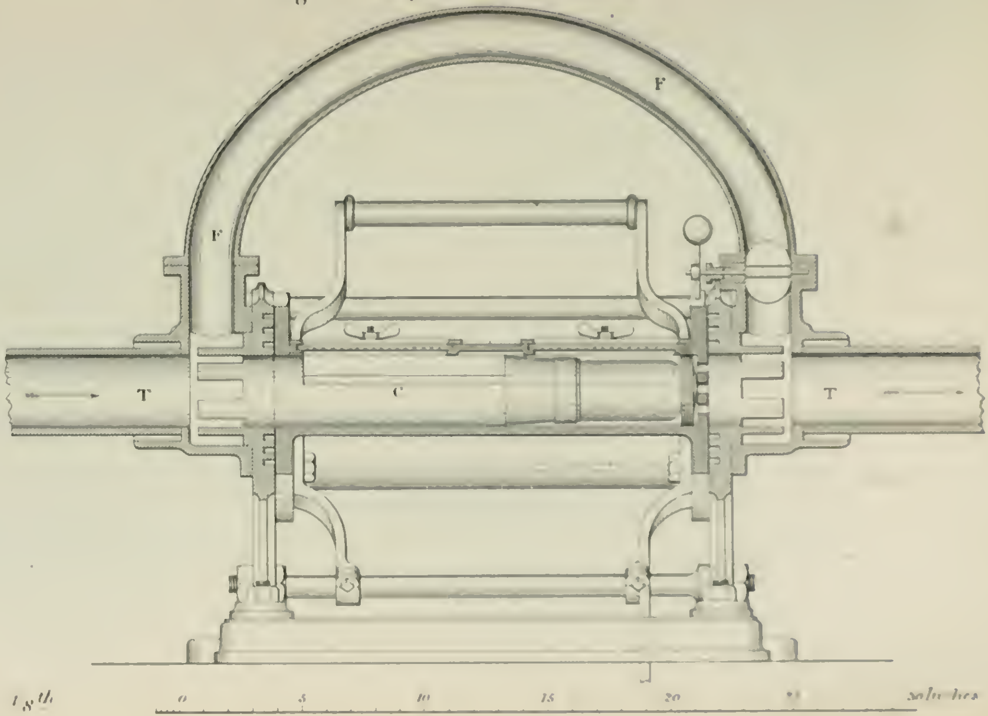


Fig. 12. *Longitudinal Section.*



(Proceedings Inst. M. E. 1872.) *Scale* 1/8th

0 5 10 15 20 25 30 Inches

STEAM JET.

Fig. 13. *Steam-Jet Exhauster applied to raise Water*

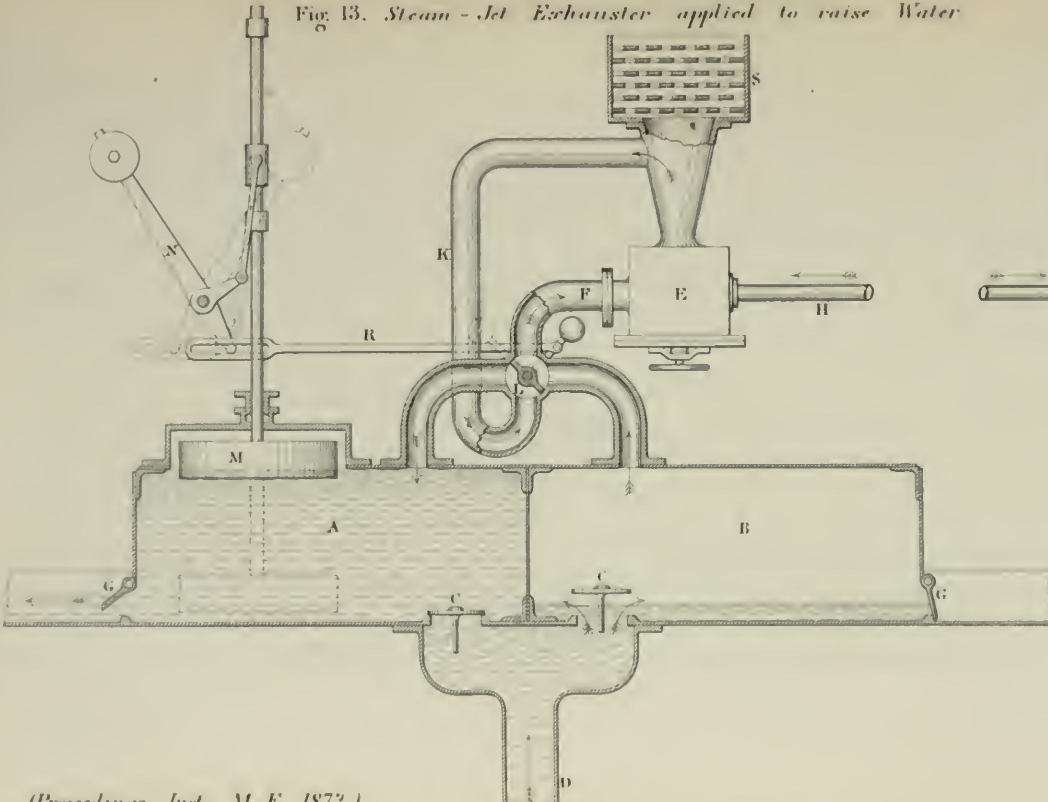
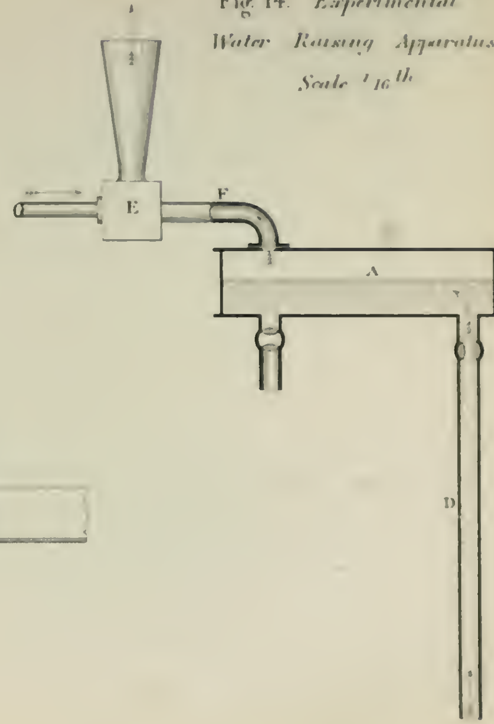


Fig. 14. *Experimental Water Raising Apparatus.*
Scale 1/16th



STEAM JET.

Steam-Jet Exhauster applied to Sugar Evaporating Pan.

Fig. 15. *End Elevation.*

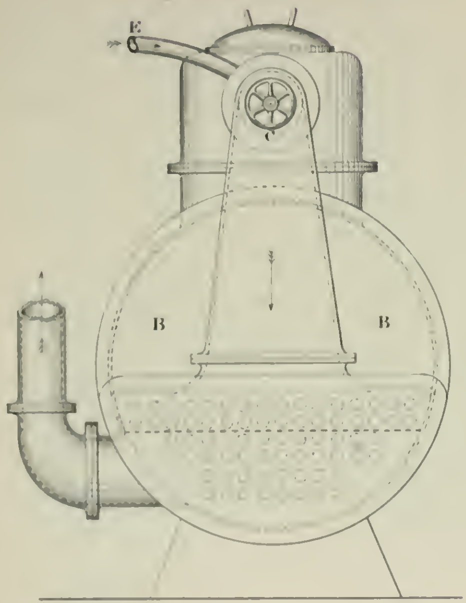
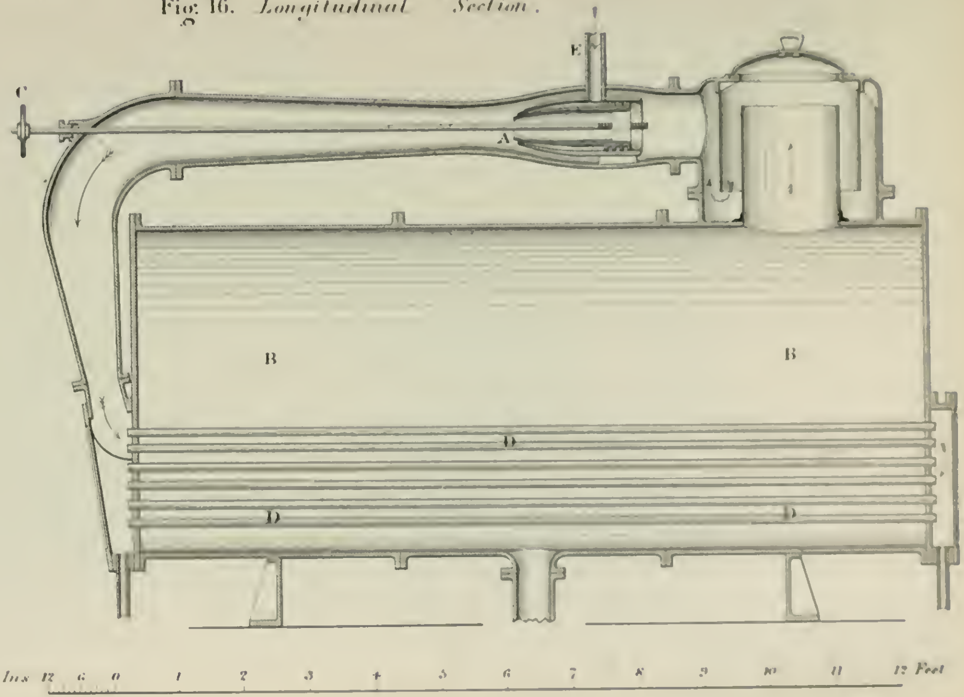


Fig. 16. *Longitudinal Section.*



 Scale 1/36th

Fig. 17. *Steam-Jet Blower applied to Gas Producer.*
Scale 1/30th

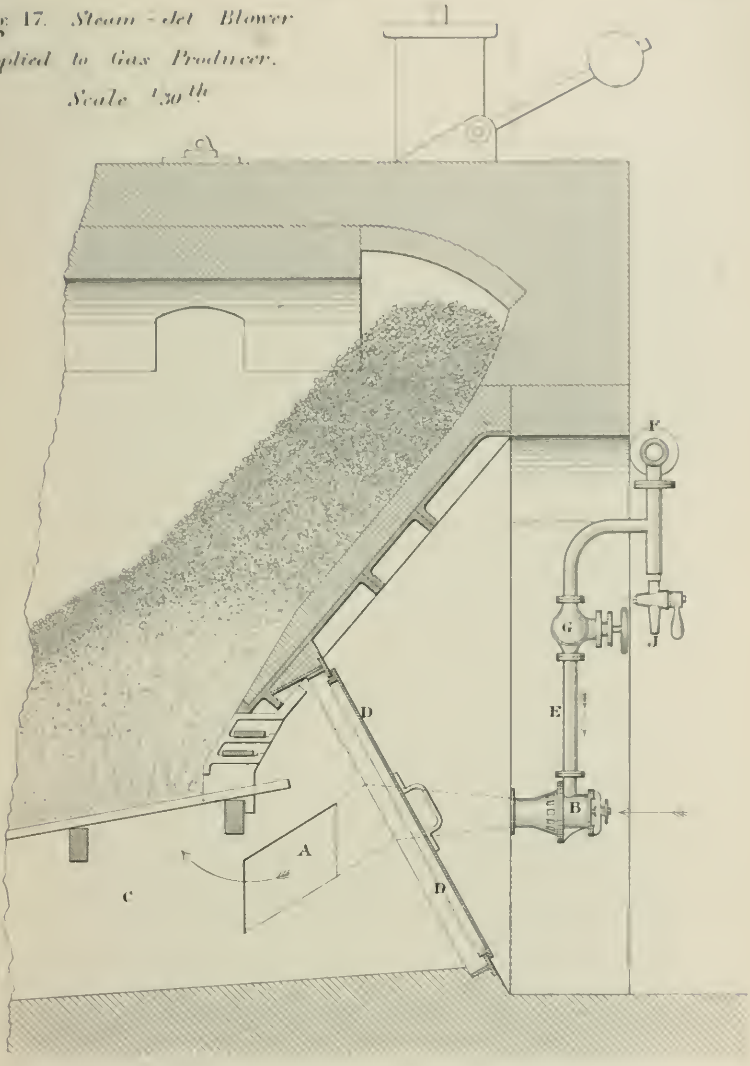
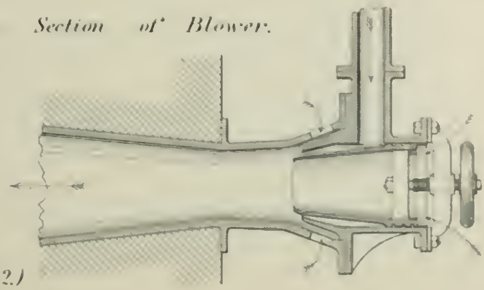


Fig. 18. *Longitudinal Section of Blower.*
Scale 1/10th



(Proceedings Inst. M. E. 1872.)

PROCEEDINGS.

2 May, 1872.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 2nd May, 1872; Charles William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members had been found to be duly elected :—

MEMBERS.

John Punshon Denton, . . .	East Hartlepool.
Herbert Fletcher, . . .	Manchester.
Wilson Hartnell, . . .	Ipswich.
John Law Hunter, . . .	Wigan.
Charles Arthur Inman, . .	Birkenhead.
Alexander Jack, . . .	Liverpool.
William Francis Jackson, . .	Sheffield.
Charles Jones, ...	Liverpool.
William Richard Sumption Jones, .	Roorkee, India.
Rowland Watkin Lewis, . .	Wolverhampton.
Augustus Stephen Lukin, . .	Carmarthen.
Richard Moon, Jun., . . .	Liverpool.
Warren Maude Moorsom, . .	Crewe.
James Noah Paxman, . . .	Colchester.
William Pole, F.R.S., . . .	London.
William John Macquorn Rankine, LL.D., F.R.S., . . .	Glasgow.

Q

HENRY ROFE, JUN., . . .	Rochdale.
FRANK BARTON SALMON, . .	Birkenhead.
THOMAS USHER, ...	Sunderland.
SIR FREDERICK MARTIN WILLIAMS, BART., M.P., ...	Perranarworthal.

The adjourned discussion then took place upon the paper read at the previous meeting, "On the Strength and Proportions of Riveted Joints, with the results of some recent experiments," (see Proceedings Inst. M. E. January 1872 page 53).

ON THE STRENGTH AND PROPORTIONS OF RIVETED JOINTS, WITH THE RESULTS OF SOME RECENT EXPERIMENTS.

By Mr. WALTER R. BROWNE, of Bristol.

(*Adjourned Discussion.*)

Mr. J. G. Wright said that, since the reading of the paper at the last meeting, some experiments had been made by his firm, to test the relative strength of the diagonal joint employed for steam boilers, as shown in Fig. 21, Plate 11, in comparison with the ordinary longitudinal joints. Two plates were tested with the diagonal joint at 45°, as shown in Fig. 24, Plate 12, and two with the longitudinal joint, as in Fig. 25; they were of Staffordshire iron, of "Monmoor Best" brand, 3 feet 6 inches long, 12 inches wide across the part tested, and $\frac{3}{8}$ inch thick; the joint was a single-riveted lap-joint with punched holes, the rivets being 13-16ths inch diameter and 2 inches pitch, and the width of lap $2\frac{1}{4}$ inches. Test pieces cut from the plates, as in Fig. 26, were also tested, to ascertain the tensile strength of the solid plates both lengthways and crossways of the grain. The experiments were conducted by Mr. Kirkaldy, and the following were the results, the plates themselves being exhibited to the meeting. The plates in each instance tore through the rivet holes along the line of the joint, and the average strength of the straight joint was 48·2 per cent. of that of the solid plate, while the average strength of the diagonal joint was 64·7 per cent. of that of the solid plate. These results were the mean of two experiments on each description of joint, and the increase of strength by the adoption of the diagonal joint was therefore 34 per cent, or in the proportion of three to four. The following table gives the particulars of the several trials:—

Experiments on relative strength of Diagonal and Longitudinal Joints.

Description of Joint.	Size of Plates.	Total Breaking Strain.	Resistance per sq. inch.		Proportionate Strength of Joint to Solid Plate.	
			Joint.	Solid Plate.		
	Inches.	Tons.	Tons.	Tons.	Per Cent.	
Diagonal at 45°	12·00 × 0·38	57·85	12·69	19·06	66·6	Mean 64·7
Do.	12·00 × 0·38	58·21	12·77	20·32	62·8	
Longitudinal	11·90 × 0·38	41·45	9·17	19·90	46·1	Mean 48·2
Do.	12·00 × 0·38	44·54	9·77	19·37	50·4	

Mr. J. Robinson enquired whether the proportions of the dimensions employed in the joints of the experimental plates now exhibited were the same as those given in the table accompanying the paper read at the last meeting. He asked also whether much difference had been found in the tensile strength of the test pieces now shown, according as the strain had been applied lengthways or across the grain of the iron; in some Yorkshire plates there was scarcely any difference in strength, in whichever direction they were tested.

Mr. J. G. Wright replied that the dimensions of the joints in his experiments did not quite agree with the proportions given in the table, the pitch being somewhat less than three times the diameter of rivet, as seen in the plates exhibited, and the diameter rather more than twice the thickness of the plate. The joints in these experimental plates were made exactly according to the proportions that were regularly followed in boilers constructed at his works. The difference of strength in the test pieces cut from the plates, according as they were tried longitudinally or crossways of the grain, was considerable; the average tensile strength of eight pieces tried longitudinally was 19·7 tons per square inch, while the average of four pieces tried crossways was only 16·8 tons, or nearly 15 per cent. less. In preparing the experimental plates for testing the joints, care had been taken that the direction in which they had

been rolled should be the one in which the strain would be thrown upon them in the testing.

Mr. J. COCHRANE observed that the question of the comparative extent to which the strength of riveted iron structures was affected by the punching or the drilling of the rivet holes had occupied his attention; and he had made a number of experiments upon it in connection with Mr. Berkley's investigation of the construction of suspension-bridge links, to which reference had been made in the paper read at the previous meeting. The object in view had been to find out for ordinary bridge-building work, not boiler work, whether in regard to strength there was really much advantage in drilling over punching: not considering whether a number of plates to be riveted together would make better work when punched or when drilled, but simply taking account of the relative strength of the individual plates or bars in a case where the punching was done with as much care as would be bestowed upon drilling. The experiments were made with bars of Low Moor and Staffordshire iron, 3 feet long, planed down to a uniform thickness and shaped to a uniform width, as shown in Fig. 27, Plate 12. The Low Moor bars were soft and fibrous, and the Staffordshire were hard and crystalline. Three experiments were tried with each description of iron, in the first of which a hole of rather less than one inch diameter was drilled in the middle of the bar; in the second the hole was punched $\frac{1}{8}$ inch too small in diameter and then rimered out to the full size; and in the third the hole was simply punched large enough to take a rivet of the same size as would be used for the two other holes. The three bars of Low Moor iron were all out of the same piece of metal, so that as far as possible the quality of the iron was uniform in them; and the result was seen to be that the drilled and punched bars were practically the same in strength, the Low Moor drilled bar being about 1 per cent. stronger than the punched bar of the same iron, and the Staffordshire drilled bar 2·3 per cent. weaker than the punched bar. The following were the particulars of the trials:—

Experiments on Bar Iron with Punched and Drilled Holes.

No. of Experiment.	Description of Iron.	Description of Hole.	See Fig. 27, Plate 12. Thickness at AB.	Width at AB.	Diam. of hole.	Sectional Area at AB.	Total Breaking Strain.	Resistance per sq. inch.
			Inch.	Inch.	Inch.	Sq. In.	Tons.	Tons.
1	Low Moor	Drilled	0·49	1·89	0·92	0·475	11·75	24·72
2	Do.	Punched and rimered	0·49	1·90	0·92	0·480	12·25	25·51
3	Do.	Punched	0·49	1·91	0·97	0·461	11·30	24·53
4	Staffordshire	Drilled	0·50	2·00	0·92	0·540	12·50	23·15
5	Do.	Punched and rimered	0·50	2·00	0·92	0·540	12·50	23·15
6	Do.	Punched	0·50	2·00	0·97	0·515	12·20	23·69

He had also tried a series of similar experiments with Staffordshire plate iron, tested both lengthways and crossways of the grain, as shown in Fig. 28, Plate 12, with the following results:—

Experiments on Plate Iron with Punched and Drilled Holes.

No. of Experiment.	Direction of Testing.	Description of Hole.	See Fig. 28, Plate 12. Thickness at AB.	Width at AB.	Diam. of hole.	Sectional Area at AB.	Total Breaking Strain.	Resistance per sq. inch.
			Inch.	Inch.	Inch.	Sq. In.	Tons.	Tons.
7	Lengthways	Drilled	0·50	2·03	0·92	0·555	11·85	21·35
8	Do.	Punched and rimered	0·50	2·02	0·92	0·550	11·90	21·64
9	Do.	Punched	0·50	2·03	0·97	0·533	11·50	21·58
10	Crossways	Drilled	0·52	1·98	0·92	0·551	10·00	18·15
11	Do.	Punched and rimered	0·52	1·98	0·92	0·551	10·00	18·15
12	Do.	Punched	0·52	2·00	0·97	0·535	10·00	18·69

The drilling was here seen to have no advantage over the punching, as affecting the strength of the plates; and the mean of the two sets of results showed that the plates were about 15 per cent. weaker when tested crossways than when tried longitudinally of the grain.

Having been considerably engaged in the manufacture of bridge work at the time of making these experiments, at the Woodside Iron Works, Dudley, it had been satisfactory to him to arrive thus at the conclusion that punching when well done left the iron practically as strong as drilling or otherwise forming the rivet holes, and was thus equally suitable for single-riveted lap-joints. But where, as frequently occurred in large girders, a number of plates, say five or six, had to be riveted together, one over another, in order to make up a sufficient thickness of metal, the case was totally different; the advantage of drilling over punching was then very great, where it was well done, as it ensured the exact correspondence of all the holes. Unless however the positions of the drilled holes were set out with perfect accuracy, so as to make them coincide correctly, it would be impossible to fill the holes properly with the rivets, on account of square shoulders being formed by the edges of the holes not coinciding, which would have the effect of nicking the rivets in those places; in such a case he believed drilled work would be decidedly worse than good punched work.

Mr. J. Robinson observed that, after so much had been said for many years about the great superiority of drilled holes for boiler work, and the serious extent to which the plates were deteriorated by punched holes, it was very reassuring to find from the experiments just described that punched plates were not really inferior in strength to drilled plates, and it appeared indeed that in three instances in those experiments punching had even shown a slight advantage in strength. This was a remarkable result, which he certainly was not prepared for; and he enquired whether it had been obtained without annealing the experimental plates after punching.

Mr. J. Cochrane replied that the specimens in his experiments had been tested without being annealed after punching.

Mr. J. Robinson mentioned that in the case of steel boiler plates he had been informed that, if the plates were annealed after punching, the strength of the metal was restored almost to what it had been before the punching operation. There appeared indeed to be a considerable discrepancy between the percentages of strength given in the table of proportions accompanying the paper, and the results of Mr. Cochrane's experiments, the percentages of strength in the paper being in every instance materially lower for punched holes than for drilled holes. He should be glad therefore to hear some explanation of the difference in the results with respect to this highly important matter. In Mr. Wright's experiments one point that struck him as requiring notice was that the strength of the straight joint had been found to be only 48 per cent. of that of the plates, which were of Staffordshire iron. This result was considerably lower than the strength assigned by the table in the paper to a single-riveted lap-joint, which amounted to 55 per cent. with punched holes and 62 per cent. with drilling. In the diagonal joint the experiments showed that the strength was brought up to 64 per cent. of that of the plates; but judging from the figures given in the table in the paper, it seemed to him that, instead of attempting to increase the strength of joint by the diagonal plan with the ordinary lap-joint, it would be preferable, in order to make the best use of the material, that the joints should be butt-joints and double-riveted, thereby raising the strength to 72 or 79 per cent. of that of the plates.

As the longitudinal joints in steam boilers were the weakest part, he hoped some means would ultimately be devised of rolling weldless cylinders of the full diameter of a boiler, so as to require only transverse circular joints, and dispense with the longitudinal joints altogether. Wheel tyres had for some years past been rolled solid without any joint whatever, and more recently gun-hoops of considerable length had been hammered or rolled without a weld; and from these operations, now successfully accomplished, it did not seem to him any very great step further to go on to the manufacture of weldless rings or cylinders of boiler plate. By that means the deterioration of strength consequent upon the drilling or punching

of rivet holes for the longitudinal riveted joints would all be got rid of, and a boiler would be obtained of the full strength of the solid plate. Such a mode of construction was a great desideratum at the present time, and he hoped it might be realised in practice before long. One result of superseding the longitudinal joints would be that thinner plates might be used; and in an instance that had recently come under his observation of a steel boiler ring of only 3 feet diameter, suitable for working at high pressure, the plate itself would have been amply strong enough if only $\frac{3}{8}$ inch thick, but had been rolled or hammered $\frac{5}{8}$ inch thick because of the difficulty of keeping up the heat until the plate was made thinner. In reference to the use of thickened-edge plates, to which allusion had been made in the paper as a means of bringing up the strength of the joint to that of the solid plate, there was no doubt that the weakness attending all ordinary joints could be obviated by that mode of construction; and this plan having been originally adopted on the Midland Railway for locomotive boilers, he enquired whether it was still adhered to for the purpose.

Mr. W. KIRTLEY replied that the thickened-edge plates continued to be used for the locomotive boilers on the Midland Railway; but the principal object in their adoption had been to do away with the angle-iron joint at the smokebox end, by getting metal enough in the plate itself at that part to allow of flanging it over for riveting to the smokebox; and on this account the thickened edges occurred only at the transverse circular joints of the boiler, and were not employed for the longitudinal joints, as proposed in the paper; the longitudinal joints were welded, which gave greater strength than any double-riveted joints.

The PRESIDENT remarked that, if the thickened edges were arranged for the longitudinal joints, the direction of rolling of the plates would then be parallel to the length of the boiler, and when put together therefore the severest strain would come upon them crossways of the grain, which he thought would be a serious objection to that mode of construction.

Mr. J. H. PERKS thought that in the experiments on the diagonal joint the strength of the joint would be increased in proportion to

the greater number of rivets it contained as compared with the straight joint; and if the number of rivets in the diagonal joint were one third more than in the straight joint, that would be sufficient to account for the increase of 34 per cent. in the strength. It appeared to him therefore, that in order to make the comparison complete, the total number of rivets in the diagonal joint should have been kept the same as in the straight joint.

Mr. J. G. WRIGHT remarked that, if the actual number of rivets had been the same in the diagonal as in the straight joint, they would have had to be spaced wider apart in the diagonal, by which the proportions of the joint would have been altered; but the object of the experiment had been to test the very same joint when straight and when placed diagonally, so as to ascertain the true effect of the diagonal position. For this purpose the transverse sectional area of the plates, at right angles to the line of strain, had been made the same in the two sets of plates tested, and all the dimensions of the joints had been kept identical.

Mr. L. OLRICK observed that there were many points of interest in the paper which had been read; and as it had been seen that different results had been arrived at in the various experiments made in connection with the subject, it was evident that there would be corresponding differences of opinion as to the proper proportions to be adopted in designing riveted joints. No doubt the principal source of discrepancies in the proportions was the difference in the quality of the plates and rivets employed, and also in the quality of the workmanship. There were indeed so many varying conditions which could not be taken into account in the construction of formulæ, that he thought any expression for the strength of boilers or other riveted work would be to some extent misleading, if adopted without careful examination of all the circumstances affecting each particular case. In consequence of the tendency at the present time to work boilers at higher pressures of steam, from 100 to 200 lbs. per square inch, and also the desire to lighten the boilers as much as possible, particularly in the case of boilers

for steam fire-engines, road steamers, and locomotives, it had now become necessary to introduce a much stronger material than wrought iron for boiler plates; and with steel plates, having a tensile strength of as much as 34 to 36 tons per square inch, it was clear that the table of proportions accompanying the paper would require considerable modifications. As the longitudinal joint in the boiler was the weakest part, and was always double-riveted in boilers exposed to high steam pressures, the mode he used for calculating the safe strength was to take a unit of that joint, equal to the pitch of the rivets, and ascertain what ratio the tensile strain thrown upon this unit bore to the tensile strength of the plate, and also to the shearing strength of the rivets; and in a properly proportioned joint these two ratios would be equal, so as to give the maximum strength of joint. Thus in designing a steel boiler of 4 feet diameter, intended to work at a steam pressure of 150 lbs. and to stand the hydraulic test up to 250 lbs., the steel plates in the shell being 3-8ths inch thick, with a tensile strength of 34 tons per square inch, he had made the joint double-riveted and the pitch of the rivets $1\frac{7}{8}$ inch, placing the rivets so as to form isosceles triangles, and had employed 11-16ths inch rivets of Low Moor iron. The strain upon this unit of joint of $1\frac{7}{8}$ inch length and of 48 inches diameter was found by multiplying 48 by $1\frac{7}{8}$, giving 90 square inches, and 90×150 lbs. $= 13{,}500$ lbs., and this divided by the 2 sides then amounted to 6750 lbs. at each side of the boiler; and the sectional area of the unit of joint being 0·4453 square inch, this multiplied by the tensile strain of 34 tons or 76,160 lbs. gave a breaking weight of 33,914 lbs., or five times the strain to be actually borne by the unit of joint. This left a much smaller margin of safety than was allowed in ordinary practice for low-pressure boilers, but it must be borne in mind that the boiler had been expressly designed in that case for working at a high pressure, and with a special view to lightness; the boiler in fact weighed only 2 tons, though capable of evaporating 48 cubic feet of water per hour. The ultimate tensile strength of the steel plate in the unit of joint of 0·4453 square

inch area would be 15·14 tons; and taking only 20 tons per square inch as the shearing strength of Low Moor iron, the total shearing strength of the two 11-16ths inch rivets in the unit of double-riveted joint would be 14·84 tons, or practically equal to the tensile strength of the unit of joint. In any boiler intended to work at an unusually high pressure he thought it was necessary to test the correctness of the proportions by this mode of calculation, in order to avoid being misled by the use of any formula not adapted to the circumstances of the case. In one instance that had come under his observation, of a steel boiler designed to work at a pressure of 180 lbs., with plates only 3-16ths inch thick, the rivets had been intended to be 5-8ths inch diameter, with $1\frac{3}{4}$ inch pitch. But on calculating the strength of the longitudinal joints in the above manner, it was found that the shearing strength of the rivets per unit of joint would be more than 12 tons, while the tensile strength of the plate would be only about 7 tons, showing a great error in the proportions. He had therefore altered the diameter of the rivets to $\frac{1}{2}$ inch, by which means their shearing strength per unit of joint was decreased to 7·85 tons, while the tensile strength of the plate was increased to 7·97 tons, thus showing that the $\frac{1}{2}$ inch rivets were the proper size for giving the greatest strength of joint in that instance. With steel plates and iron rivets it was indeed particularly important that the diameter of the rivets should be made large enough, on account of the liability of the hard steel plates to indent the softer metal of the rivets, as alluded to in the paper, especially when a boiler was subjected to so severe a test as a hydraulic pressure of 250 lbs. per square inch.

From the proportion given in the table for the pitch of the rivets in ordinary single-riveted lap-joints, namely three times the diameter of rivet, it appeared that with $\frac{3}{8}$ inch plates and $\frac{3}{4}$ inch rivets the pitch should be $2\frac{1}{4}$ inches. In practice however, with rivets of that size, he thought 2 inches was as much as was desirable for the pitch of the rivets, even in boilers working only at 60 to 70 lbs. pressure; for with a greater pitch he had found that if the caulking were done carelessly the plate was liable to be raised between the rivets, in

which case it was impossible afterwards to get it down flat again or to make the joint tight at that place. The same remark would apply still more strongly to the case of double-riveted joints with the pitch equal to $4\frac{1}{2}$ times the diameter of rivet. In the steel boiler that he had mentioned, with 11-16ths inch rivets and $1\frac{7}{8}$ inch pitch, the joints were perfectly tight under the hydraulic pressure of 250 lbs. It frequently happened that caulking was resorted to as a means of concealing the defects of inferior workmanship; and this was a point to which he thought particular attention should be paid, as caulking when carried too far was a great source of damage to the plates. The proportions arrived at in the paper for single-riveted lap-joints had been stated to agree closely with Sir William Fairbairn's table in extensive use, for plates under $\frac{1}{2}$ inch thickness; but he noticed that the agreement did not hold good with regard to the pitch of the rivets for plates 5-16ths and 3-8ths inch thick, which according to the rule given in the paper should be 1·87 inch and 2·25 inch respectively, but in that table were put down as 1·63 inch and 1·75 inch. These dimensions for the pitch he concurred with the author of the paper in considering too small for plates of those thicknesses, and they would have the effect of unduly weakening the plates by bringing the rivet holes too near together.

The want of sufficient attention to the circumstance that the strain upon the longitudinal joints of a boiler was double of that upon the transverse circular joints, as pointed out in the paper, had been remarkably exemplified in a boiler shown at last year's International Exhibition in London, which was constructed with the transverse joints double-riveted, while the longitudinal joints were only single-riveted. There was no doubt the diagonal seam would give a much stronger boiler than the ordinary longitudinal joint; but he thought a greater amount of labour would have to be expended in the construction of the diagonal-jointed boilers, on account of the difficulty of bending the plates so as to make their edges fit together correctly at the required inclination. It appeared to him also that the cutting of the diagonal plates at the ends of the boiler, for the purpose of finishing off the ends square across, would occasion a

considerable amount of waste. On these accounts the diagonal-jointed boilers seemed likely to be somewhat more expensive in manufacture, which might counterbalance the advantages of their construction.

From the table of proportions given in the paper it appeared that in all cases of double-riveted joints chain riveting had an advantage over zigzag riveting in respect of strength. The general practice however he believed was to have zigzag riveting, at any rate in boiler work; and when the rivets were so arranged as to form equilateral triangles in the zigzag riveting, he considered a stronger joint was obtained than in chain riveting, because in the latter, with the rivets in the second row placed immediately behind those in the first, it was found that when a severe strain was put upon the joint there was a tendency for the plate to split longitudinally from the rivets in the first row to those directly behind them in the second. This he believed was the objection felt by boiler makers to chain riveting; and another consideration was that, in the event of any flaw in a plate, which generally did not extend far, there was a better chance of the rivet holes missing it in zigzag riveting, or at any rate of getting only one rivet hole in the weak part; whereas in chain riveting, if one rivet occurred at the flaw, the probability was that the same would be the case with the rivet behind it, on account of the flaw running usually in the direction of rolling of the plate, and the joint would consequently be less secure at that part. A practical difficulty met with in the use of zigzag riveting occurred at the corners of the plates in boiler work, where the double-riveted longitudinal joint and the single-riveted transverse joint came together. In setting out the rivet holes on the zigzag method it was found that the last rivet at each end of the inner row could not be got in at its proper place, on account of its coming just upon the inner edge of the lap of the transverse joint. This last rivet had therefore either to be omitted altogether; or else the pitch of the inner row of rivets was gradually diminished towards the ends, so that what had been zigzag riveting in the middle of the longitudinal joint became chain riveting at the ends. The omission of the last rivet seemed an undesirable mode of

meeting the difficulty, as it would leave a weak place at that part; and he should be glad to know whether in such cases any practical objection had been experienced in boilers so constructed, on account of deficiency of strength at the corners of the joints.

Mr. E. B. Marten said that in the case of stationary boilers, to which his own experience chiefly referred, it was not so generally necessary to have the very strong joints required for locomotive boilers working at higher pressures. The common experience in stationary boilers with the joints that were exposed to the fire was that the more iron those joints contained the more readily were they affected by the action of the fire; and on this account he thought that butt-joints with single or double cover-strips were not so suitable for stationary boilers as a single-riveted lap-joint, which, although a much weaker joint in itself, certainly appeared to stand the fire better, because the water got to it more readily than to the others and preserved the metal from overheating. He had not had much experience of double-riveting exposed to the fire, but he believed where it was not so exposed it had generally stood well, and he had not met with any instance of a boiler giving way at a double-riveted joint. At the corners where the longitudinal and transverse seams came together, the joint was so exceedingly strong that the omission of the last rivet in zigzag riveting would he thought be practically immaterial.

From what he had seen of the diagonal-jointed boiler, that mode of construction seemed to him to recommend itself, not on account of the number of rivets in the diagonal joint giving it an advantage over a longitudinal joint, but simply because the longitudinal joint was the weakest in a boiler; and therefore if it were got rid of by means of one running midway between the longitudinal and transverse directions, a boiler so constructed must evidently be stronger. Only one explosion of a diagonal-jointed boiler had come under his notice, and the line of fracture in that case ran through the body of the plates and not along the joints at all. He had tested small models of boilers made on that plan, but had not been able to keep them sufficiently tight to burst them; a

small boiler had however been burst by Mr. Wright, and its strength had been found to be more than 40 per cent. greater than that of a similar boiler with longitudinal joints.

With regard to the values assigned in the paper for the shearing, crippling, and tensile strength of the rivets and plates, he presumed the variation of these values in different classes of iron would cause considerable variation in the results derived from the expressions which had been given for the proportions of riveted joints; and it would therefore be desirable to ascertain correctly the exact shearing, crippling, and tensile strength of the particular iron employed in any work, in order to arrive at the proper proportions for the riveted joints.

Mr. J. G. Wright mentioned that in the trials he had made for ascertaining the strength of the diagonal-jointed boiler he had constructed small experimental vessels 18 inches in diameter, $\frac{1}{8}$ inch thick, and 3 ft. 6 ins. long, and had burst them by hydraulic pressure. One was made with a longitudinal joint, a second with a diagonal joint at 45° and single-riveted, a third with a double-riveted diagonal joint at the same inclination, and a fourth with a single-riveted diagonal joint inclined at an angle of 60° to the length of the boiler. They were all made with drilled holes, and put together in the most careful manner possible, and he had great difficulty in bursting them, on account of the difficulty of getting the joints perfectly tight under the very severe pressure. The results arrived at were that the vessel with the single-riveted diagonal joint at 45° was about 45 per cent. stronger than the one with the longitudinal joint; the double-riveted diagonal joint was 60 per cent. stronger, and the joint at 60° gave an increase of strength of as much as 75 per cent. One of the diagonal-jointed boilers of 3 ft. 6 ins. diameter and 11 ft. length, at present at his works, had been tested by hydraulic pressure up to 350 lbs. per square inch, and had proved perfectly tight under that severe test. In the manufacture of the boilers there was not any difficulty in the bending of the plates, nor any waste in cutting the plates for finishing off the ends of the boiler; by cutting a

rectangular plate diagonally across at the angle of 45°, one half was made to fit at one end of the boiler, and the other half at the other end; there was consequently no more waste and very little increase of expense in the construction of the diagonal-jointed boilers as compared with the ordinary mode of construction. The number of rivets in the diagonal joint was no greater per foot run than in a longitudinal or transverse joint, the pitch being kept the same for the diagonal joint.

Mr. H. A. Fletcher remarked that, in reference to the comparative advantages of lap joints and butt joints for boiler work, it should be borne in mind that in lap joints there was an element of weakness which was not taken into account in any of the experiments referred to in the paper. This was owing to the departure from the true cylindrical form, which was necessitated by the use of the lap joint; but with the butt joint there was no such difficulty, the plates of the boiler shell then forming a perfect circle.

Mr. Browne said he was aware there was still considerable difference of opinion as to the comparative advantages of lap joints and butt joints, but he had himself been led to the conclusion that there was not much to be gained by the use of butt joints. It was urged in favour of the butt joint for boiler work that the preservation of the true cylindrical form of the boiler rendered that joint stronger than the lap joint; and that in the ordinary lap joint in boilers the tension on the outside of the outer plate was considerably more than that on the inside of the inner plate. This however was not borne out by experiment; and having examined a great number of experiments made on the subject, he had found the difference of strength was comparatively small between butt joints and lap joints. The ordinary mode of making experiments upon joints for boiler work was undoubtedly unfavourable to lap joints and favourable to butt joints, because they were made with flat plates by tearing the joint apart by means of two opposite forces acting exactly in line with each other; the result therefore was that in a lap joint the first effect of the strain was to pull the two plates into line with each other by bending them at the joint, which must

necessarily produce a weakening of the joint, and cause it to yield under a lower strain than that required to tear asunder a butt joint. In a cylindrical boiler however he did not think there was any such tendency to strain the lap joints unduly in that way, and the pressure being radial all round the boiler the only tendency was to tear the plate between the rivets or to shear the rivets; and accordingly he did not see any great advantage in using butt joints for boiler work. It must also be taken into account that, even in the event of a lap joint undergoing a slight change of shape under the action of the internal pressure in a boiler, the very yielding of the material tended to bring it into the cylindrical form, which was the form best adapted for resisting the strain. A result of some interest had been furnished by an experiment he had made with an iron bar $\frac{1}{4}$ inch square, screwed down at the ends upon bearings 2 feet apart, and loaded in the centre for the purpose of breaking it; but though loaded with several times the weight by which according to the ordinary rules for transverse strength it ought to have been fractured, it had not broken, simply because it had deflected three or four inches under the load, and when bent at that angle it became like part of the shell of a boiler, and the whole sectional area of the bar was brought into tension, instead of being half in tension and half in compression; and it would thus have required a greatly increased strain to break it.

With regard to the practical application of the proportions given in the paper for riveted joints, it was certainly requisite that the strength of the particular class of iron employed in any case should be ascertained by experiment, in order that the proportions given might be modified to the extent necessary for rendering them correctly applicable. In the expressions given in the paper he had endeavoured to embody the mean values of the constants involved, as derived from experiments made with different descriptions of iron, so as to arrive at a pretty fair average for the results. The experiments that he had made use of for the purpose were entirely confined to iron plates and rivets, and therefore the rules for proportioning the joints of steel plates would be somewhat different. Having himself had no experience yet of steel boilers, which he

considered were still on their trial, he should be glad to hear the results of their working and of any experiments bearing upon the strength of the joints, which would be of great use. The shearing strength that had been mentioned of 20 tons per square inch for iron rivets in steel plates would he hoped be confirmed by further actual trial; this was a higher value than that obtained in Mr. Henry Sharp's experiments, which gave an average of only 18·68 tons per square inch, on account of the steel plates being found to cut into the iron rivets much more readily than iron plates did.

In double-riveted joints, with either zigzag or chain riveting, there was no doubt a limit to the pitch of the rivets, which it would not be well to exceed, because the rivets must be close enough together to enable the plates to stand the caulking. Within this limit he thought chain riveting was preferable to zigzag, inasmuch as it required less width of lap or cover, while giving exactly the same strength; unless indeed it were found that in punching one hole immediately behind another there was any tendency of the plate to crack between them.

The higher proportionate strength shown in the table accompanying the paper for joints made with drilled rivet-holes, as compared with those in which the holes were punched, was not the result of experiment, as he had not made any experiments upon plates with drilled holes; but with punched holes it was certainly the usual experience that the strength of the net sectional area of the plate was considerably less than that of an equal section of unpunched plate. In drilled plates he had assumed that this deterioration of strength would not exist, as the injury done to the plate by punching was not done by the action of drilling; and in the calculation of the table he had therefore taken the strength of the plate between the drilled holes as equal to the full strength of the solid plate. After the results of Mr. Cochrane's experiments however, it was no doubt desirable that this point should be more completely ascertained, because if drilling had really no advantage in strength over punching, it would be a mistake to recommend its adoption. It should be observed that in those experiments special care seemed to have

been taken that the punching should be as good as possible; and in punching only one or two holes for special trial, the work would probably be much better done than where a number of holes had to be punched, as in ordinary work. One reason indeed for according the superiority to drilling was that it was easier to make good work in drilling than in punching, irrespective of the effect of either operation upon the strength of the plates themselves. In punched work it was well known that as a matter of fact a great many of the holes did not correspond, and required to be rimered out in order to get the rivets in; whereas when the plates were drilled, it was hardly possible that the holes should not fit each other with perfect accuracy. If really good work could be ensured in punching, there might possibly be no material advantage in drilling.

In the use of thickened-edge plates for boilers, with regard to the objection felt to the employment of the thickened edges for the longitudinal joints, on the ground that the strain upon these joints would then be crossways of the grain of the iron and consequently the plates themselves would be weaker, it was true that most experiments upon the strength of boiler plates, when tested longitudinally and transversely of the grain, had shown them strongest in the former direction; but this was simply in consequence of the ordinary mode of manufacture, and having been himself engaged in the manufacture of boiler plates, he had every reason to believe that, when the piling of the slab was properly arranged in cross layers, plates could be produced that would be as strong in one direction as in the other.

From the experiments made upon the strength of the diagonal-jointed plates, and from the information which had been given respecting the manufacture of boilers with that form of joint, he had come to the conclusion that both in theory and practice the diagonal-jointed boiler possessed a decided advantage. It should however be observed that the increase of 34 per cent. in strength of the joint, as shown by the experiments on the diagonal-jointed plates, represented rather more than the real gain obtained in a boiler so constructed, because in the testing machine the experimental plates

had been subjected solely to the single tensile strain applied at 45° inclination to the diagonal joint; whereas in a boiler the diagonal joint had to sustain two tensile strains acting at right angles to each other, and each at 45° to the joint, one of these strains being double the amount of the other. The effect was consequently a resultant strain, bearing to the greater of the two component tensions the ratio of $\sqrt{\frac{5}{2}}$ to 2, or 1·58 to 2·00, so that the strength of the diagonal joint was increased in the ratio of 100 to 127, as compared with that of the ordinary longitudinal joint; and 27 per cent. was therefore the limit to the increase of strength that could be obtained in a boiler by the adoption of the diagonal joint.

The great loss of strength involved in any description of riveted joint was a subject to which it appeared to him very desirable that attention should particularly be drawn. The experiments on Mr. Wright's plates now exhibited, possessing a tensile strength of 19·7 tons per square inch, showed that in the ordinary single-riveted lap-joint the strength was only 48 per cent. of that of the solid plates; and by the calculations given in the paper, taking the proportions which had been arrived at as the most advantageous, it was seen that 55 per cent. was the highest result which could be obtained with that description of joint. If the present paper and discussion should lead to greater attention being paid to this subject, he should feel that a very desirable object had been gained.

Mr. L. Olrick enquired whether in the calculations given in the paper for the proportionate strength of riveted joints the effect of the friction produced by the grip of the rivet heads had been taken into account. In experiments made upon plates riveted together with oval rivet-holes, he understood it had been found that a force of as much as 4 to 5 tons per square inch of section of rivet was required to make the plates slide upon each other and bring the rivets to their bearing in the oval holes; and the friction would therefore increase to that extent the strength of riveted joints.

Mr. Browne replied that the experiments upon which he had based the conclusions arrived at in the paper had all been made upon actual riveted work; and consequently the full effect of the friction produced by the rivets was included in the results.

The President considered the paper which had been read was a highly interesting one, and the discussion had brought out several important points. He was himself strongly impressed with the value of the diagonal joint for riveted work. At first sight it would seem that in the diagonal riveting the strength of the joint would be increased in proportion to the increase of length of the seam, because each rivet would have a smaller longitudinal section of the boiler to deal with, and therefore there would be less strain upon each rivet, the total number of rivets to resist the strain being increased in the proportion of the length of the diagonal seam, or about 5 to 7 for the inclination of 45°. It had however been pointed out that in the case of a boiler there was a deduction to be made, in consequence of the joint having to sustain, in addition to the transverse strain, a longitudinal strain of half the amount. There still remained however a sufficient increase of strength in the diagonal joint, as compared with the ordinary longitudinal joint, to make it well worth while to adopt that form of construction; and another recommendation of the diagonal joint was that it was not so much weakened by a flaw of equal extent along the line of rivets as the longitudinal joint would be. The plan of increasing the strength of a riveted joint by the use of thickened-edge plates did not appear to him to be applicable with advantage to the longitudinal seams of an ordinary wrought-iron boiler, because the greatest strain would then come upon the plate in a direction at right angles to the grain or fibre of the iron. It had indeed been stated that plates well made were as strong transversely as longitudinally, and no doubt this was the case with finely crystalline qualities of iron, just as with steel; but the more fibrous descriptions of iron were certainly stronger in the direction of the fibre than transversely, and with such plates therefore the thickening of the edges for the longitudinal seams did not appear to him to be advisable.

He proposed a vote of thanks to Mr. Browne for his paper, which was passed.

The following paper was then read:—

ON A STEAM JET FOR EXHAUSTING AIR &c., AND THE RESULTS OF ITS APPLICATION.

By C. William Siemens, Esq., D.C.L., F.R.S., President.

The Steam Jet, although it has long been used with such remarkable success for producing a current of air to form an artificial draught in locomotive and portable engine boilers, has hitherto been extremely limited in its application to other purposes; for though its simplicity for the propulsion of air is a great recommendation, the effect realised from a given expenditure of steam has been extremely unsatisfactory, in comparison with the results of the same steam in working an engine and air pump; nor has sufficient pressure of air been obtained from the steam jet to render it applicable for pneumatic propulsion or the production of furnace blast. The form and application of the steam jet having remained hitherto essentially the same as in the original steam blast of the locomotive in 1829, it occurred to the writer that much might be done to improve its effect by a judicious arrangement of the parts, so as to avoid eddies in the combined current of steam and air, and also to utilise more completely the initial momentum of the steam. In carrying out this idea, the first results obtained about a year ago were sufficiently encouraging; and by gradually recognising more fully the points of essential importance, the writer succeeded in constructing a steam-jet exhausting apparatus capable of producing a vacuum of as much as 24 inches of mercury, with steam of only three atmospheres effective pressure; and a useful effect has been obtained from the steam, equal to that of the ordinary fan blast, and even of the steam engine and pump.

This improved steam jet is shown half full size in the longitudinal and transverse sections, Figs. 2 to 5, Plates 13 and 14. A very thin annular jet of steam is employed, in the form of a hollow cylindrical column, discharged from the annular orifice between the two conical nozzles A and B, the steam being supplied from the pipe C into the space between the two nozzles. The inner nozzle A can be adjusted up or down by the hand screw D, so as to diminish or increase the area of the annular orifice between the two nozzles, for regulating the quantity of steam issuing. The air to be propelled by the steam jet is admitted from the pipe E through an exterior annular orifice surrounding the steam jet, and also through the centre of the hollow jet. The tube G, into which the steam jet issues, is made of conical shape at the bottom, so as to form with the outer nozzle B a rapidly converging annular passage for the entrance of the air; and the width of this air passage is regulated by adjusting the nozzle B by means of the nut H at bottom. The tube G continues to converge very gradually for some distance above the jet orifice, the length of the convergent portion increasing with the width of the outer annular air orifice, and also with the steam pressure employed; the most advantageous length varies from 12 to 20 times the width of the annular air orifice, the object being to ensure the complete commingling of the steam and air within the length of the mixing chamber G, beyond which the tube gradually increases in diameter in a parabolic curve to the upper end, as shown in Fig. 1. A tapering spindle I is sometimes fixed in the centre of the inner nozzle A, and carried up through the mixing chamber G, for the purpose of preventing reflux through the centre of the combined current.

The rationale of this arrangement is as follows. First, by gradually contracting the area of the air passages on approaching the jet, the velocity of motion of the entering air is so much accelerated before it is brought into contact with the steam, that the difference in the velocity of the two currents at the point where they come together is much reduced, and in consequence the eddies which previously impaired the efficiency of the steam

jet are to a great extent obviated, and a higher useful result is realised. Secondly, by the annular form of the steam jet the extent of surface contact between the air and the steam is greatly increased, and the quantity of air delivered is by this means very much augmented in proportion to the quantity of steam employed; also the great extent of surface contact tends to diminish eddies. Thirdly, by discharging the combined current of steam and air through the expanding parabolic delivery funnel of considerable length, in which its velocity is gradually reduced and its momentum accordingly utilised by being converted into pressure, the degree of exhaustion or compression produced by the steam jet is very materially increased under otherwise similar circumstances.

The results of a long series of experiments with this form of steam jet, both for exhausting and compressing air, have led to the following conclusions:—

First, that the quantity of air delivered per minute by a steam jet depends upon the extent of surface contact between the air and the steam, irrespective of the steam pressure, up to the limit of exhaustion or compression that the jet is capable of producing.

Second, that the maximum degree of vacuum or of pressure attainable increases in direct proportion to the steam pressure employed, other circumstances being similar.

Third, that the quantity of air delivered per minute, within the limits of effective action of the apparatus, is in inverse relation to the weight of air acted upon; and that a better result is therefore realised in exhausting air than in compressing it.

Fourth, that the limits of air pressure attainable with a given pressure of steam are the same in compressing and in exhausting, within the limit of a perfect vacuum in the latter case.

The principle of action of the steam jet had received but little attention until the time of the interesting question raised in 1858 by the invention of the Giffard Injector, by means of which water can be forced into a high-pressure boiler by a jet of steam of the same pressure, or even of greatly inferior pressure. The physical

explanation of this remarkable fact, which was first attempted the writer believes in a discussion of the subject at this Institution (see Proceedings Inst. M. E. January 1860 page 39), is based on the principle of conservation of momentum in the combined jet of steam and water; but although the source of power in both cases is a steam jet, the mode of action in the water injector differs essentially from that of the steam jet applied to propulsion of air, as in the former case the steam is condensed by contact with the water, and ceases to be an elastic fluid at the moment of issue, while in the latter the steam forms with the air a combined elastic stream.

A very elaborate investigation of the ordinary steam jet applied to propulsion of air was given by Professor Zeuner of Zurich in 1863, showing the effects produced by varying the relative areas of inflow of the air and steam, and varying the steam pressure employed. These theoretical enquiries, which were supported by elaborate experiments, have since been considerably advanced by Professor Rankine, who has shown that in the combined stream a considerable portion of the total momentum is lost, and that the relative proportion of this loss increases with the difference of velocity between the component streams.

The form of steam jet employed in Zeuner's experiments consisted of a contracted steam orifice, directed upwards in the line of the axis of a vertical delivery tube, but terminating a little below the base of the tube; the length of the tube relatively to its diameter was found to be only of minor importance. Exhaustion of air was effected at the lower end of this delivery tube, or compression of air at the upper end. The greatest extent of exhaustion or compression that was maintained with steam of two atmospheres effective pressure amounted to 7 inches of mercury; and 100 volumes of steam measured at atmospheric pressure were expended in compressing only 7 volumes of air to the above pressure of about $\frac{1}{4}$ atmosphere. With a reduced orifice for the steam jet, a compression of $3\frac{1}{4}$ inches of mercury was maintained, and 37 volumes of air were compressed by the expenditure of 100 volumes of steam measured at atmospheric pressure.

In a corresponding experiment made with the improved steam jet shown in Plate 13, maintaining a vacuum of $8\frac{1}{4}$ inches of mercury, 137 volumes of air were removed by the expenditure of 100 volumes of steam, both measured at atmospheric pressure; which gives a result of nearly four times the useful effect that was obtained in Zeuner's apparatus.

The following Table 1 gives the results obtained with the steam jet arranged as an Exhauster for drawing air out of a closed vessel having a capacity of 225 cubic feet. The four last columns show the vacuum produced in the vessel, measured in inches of mercury, when the exhauster had continued in action for the length of time indicated in the first column. The pressure of steam in the boiler was 45 lbs. per square inch, and the sectional area of the annular steam orifice of the jet was varied from 0·05 to 0·20 square inch.

TABLE 1.

Experiments with Steam-Jet Exhauster exhausting air from a closed vessel.

Time of action.	Area of annular orifice of Steam Jet			
	0·05 sq. in.	0·10 sq. in.	0·15 sq. in.	0·20 sq. in.
Minutes.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.
1	9	10	$9\frac{1}{4}$	$8\frac{1}{2}$
2	13	$13\frac{1}{2}$	$13\frac{1}{2}$	13
3	$14\frac{1}{2}$	15	$16\frac{1}{4}$	$15\frac{3}{4}$
4	$15\frac{1}{2}$	$15\frac{1}{2}$	$17\frac{1}{4}$	17
5	$15\frac{3}{4}$	$15\frac{5}{8}$	18	$17\frac{3}{4}$
6	...	...	$18\frac{1}{2}$	$18\frac{1}{4}$
7	...	...	$18\frac{3}{4}$	$18\frac{1}{2}$

Another set of experiments has been tried with the steam jet used as a Blower for compressing air into the same closed vessel of 225 cubic feet capacity. For this purpose the conical delivery funnel of the steam jet was connected with the vessel by means

of a 3 inch pipe containing a stop-cock; and into this pipe was delivered a small jet of cold water through a pipe of $\frac{1}{2}$ inch diameter under a pressure of 40 lbs. per square inch, with the object of condensing the steam from the blower, the water being turned on simultaneously with the starting of the steam jet. The sectional area of the outer annular air passage in the blower was 0·20 square inch, and of the inner air passage in the centre of the jet 0·16 square inch, making a total of 0·36 square inch of air section. The sectional area of the annular steam jet was 0·07 and 0·12 square inch in the different experiments, the results of which are given in the following Table II:—

TABLE II.

Experiments with Steam-Jet Blower compressing air into a closed vessel.

Time of action.	Area of annular orifice of Steam Jet.		
	0·07 sq. in.	0·12 sq. in.	0·07 sq. in.
	With Condensing Water.	*With Condensing Water.*	*Without Condensing Water.*
Minutes.	PRESSURE. Inches of Mercury.	PRESSURE. Inches of Mercury.	PRESSURE. Inches of Mercury.
$\frac{1}{3}$	6	5	9
$\frac{2}{3}$	10	9	11
1	12	12	14
$1\frac{1}{3}$	13	16	15
$1\frac{2}{3}$	$13\frac{1}{2}$	19	$15\frac{1}{2}$
2	14	$21\frac{1}{2}$	16
3	15	24	$16\frac{3}{4}$
4	$15\frac{1}{2}$	25	$16\frac{3}{4}$
5	15	$24\frac{1}{2}$	12
6	$14\frac{3}{4}$	$24\frac{1}{4}$	11
7	$14\frac{3}{4}$	$23\frac{3}{4}$	$10\frac{1}{4}$
8	$14\frac{3}{4}$	$23\frac{1}{2}$	10
Final temperature of air in vessel	113° F.	...	158° F

At the end of the fourth minute the stop-cock was closed, shutting off the steam-jet blower, and at the same time the condensing water was shut off; it will be seen that the pressure in the vessel then fell slightly, owing to the condensation of the small residue of the steam from the jet. In the third experiment, in which no condensing water was used, the fall of pressure was more considerable, and the final temperature of the air in the vessel was higher. The steam pressure in the boiler was 50 lbs. per square inch.

The following are some of the applications which have already been made or are in course of being made of this improved form of steam jet.

Pneumatic Despatch Tubes.—First, to the working of Pneumatic Despatch Tubes. For this purpose the steam jet has a great advantage over an ordinary steam engine and air pump in first cost and simplicity, and also in taking up much less space: the latter advantage being of the greatest value when it is required to work pneumatic despatch tubes in crowded localities where it is difficult to obtain room for steam machinery. A pneumatic tube 3 inches in diameter, to be worked on the circuit system arranged by the writer, has been laid down by the postal authorities in London, from the Central Telegraph Station in Telegraph Street to Charing Cross and back, with intermediate stations at the General Post Office and near Temple Bar. The length of tube forming the whole of this circuit is 6890 yards, or nearly four miles. This line was designed to be, and is, as a rule, worked by means of an air pump A, driven by a steam engine, as indicated in the diagram, Fig. 6, Plate 15. The pump draws air out of a vacuum vessel V, and forces it into a pressure vessel P, both vessels being in connection with the pneumatic tube T, as indicated by the arrows. These vessels are introduced in order to prevent the pulsations of the engine from being felt in the working of the tube, and are of course unnecessary when the tube is worked by means of the steam jet. The piston carriers, which are propelled through the tube by the vacuum produced, are of the cylindrical form shown in Figs. 7 to 9, Plate 16; they consist of a gutta-percha case covered

with drugget or felt, and are made an easy fit in the tube, so as to slide freely through it.

This line has been experimentally worked by means of three steam-jet exhausters, similar to the one shown in Fig. 2, arranged in the manner shown at E E E, Fig. 6, so that all three draw air out of the same tube F, the steam being supplied to them by the steam pipe G. When working with these three exhausters, the mean speed of a piston carrier travelling through the tube from Charing Cross to Telegraph Street was $14\frac{1}{3}$ miles per hour. The vacuum maintained in the tube was equivalent to 10 inches of mercury, the steam pressure being 40 lbs. per square inch; and the quantity of coal consumed under the boiler was 56 lbs. per hour. In the case of long lines of pneumatic tubes, it will be better to work them with an exhauster at each end.

For placing the piston carriers into the tube or taking them out of it at the different stations S S, Fig. 6, without interrupting the current of air, the intercepting apparatus shown in Figs. 10 to 12, Plates 16 and 17, is employed. This consists of two short tubes B and C, fixed side by side in a rocking frame, each of which can be brought into line with the circuit tube T at pleasure. Each end of the rocking frame is faced, and works against the faced side of a boss on the end of the circuit tube. Three annular grooves are turned in the faced side of the boss round the end of the circuit tube, for the purpose of preventing the leakage of air between the ends of the rocking frame and the bosses. One of the tubes B in the rocking frame is used as the sending or "through" tube, and is simply a hollow cylinder of the same internal diameter as the circuit tube T; when this is in line with the circuit tube, a carrier can pass through the instrument without being stopped, and this tube is also used for putting carriers into the circuit. The other or receiving tube C has a perforated diaphragm at its down-stream end, so as to arrest the carriers when it is placed in line with the circuit tube, as in Figs. 11 and 12. This receiving tube is D shaped in section, with a flat cover, which can be taken off if required; as for instance, to remove carriers, in the event of two arriving at once and so preventing the

rocking frame from being moved. The flat cover is furnished with a pane of glass, to enable the attendant to see when a carrier has arrived. In order to prevent the continuous flow of air in the whole circuit of tube from being impeded by the receiving tube being left in the circuit after it has caught a carrier, a by-pass F for the air is provided, which communicates with the circuit tube T at both ends of the instrument. A sliding rod H, Fig. 10, held on suitable supports, is supplied for pushing the carriers out of the receiving tube, when intercepted and brought out of the circuit. The manipulation for sending and receiving the carriers is exceedingly simple; and a treadle is provided for moving the rocking frame with the foot.

Raising of Water.—A second application of the improved steam jet is to the Raising of Water. For lifts not exceeding 20 feet a steam-jet exhauster could be used with advantage in situations where the erection of an engine and pumps would be attended with considerable cost and inconvenience, or where the work to be done was of short duration or of an occasional character, such as in draining lands, &c. When employed for this purpose the exhauster would be applied in the manner shown in Fig. 13, Plate 18, where A and B are two closed air-tight chambers fixed at a height of from 16 to 20 feet above the level of the water to be raised; inlet valves C are provided in the bottom of the chambers for the water to enter from the suction pipe D, and outlet valves G for the discharge of the water raised. The exhauster E, supplied with steam by the pipe H, exhausts the air from the chambers A and B through the pipe F, which is provided with a reversing valve L for placing the exhauster in communication with each of the two chambers alternately; and the delivery end of the exhauster, which may be closed by a valve, also communicates with the chambers through the pipe K and the same reversing valve L. The chamber A is provided with a float M, the rod of which works by tappets the tumbling lever N, and this throws over the weighted lever of the reversing valve L by means of the looped rod R.

The action of the apparatus is as follows. While the exhauster is drawing the air out of the chamber B through the pipe F, as shown in Fig. 13, thus causing the water to rise into the chamber through the suction pipe D under the pressure of the atmosphere, the discharged jet of combined steam and air from the exhauster passes through the pipe K into the top of the other chamber A, which is full of water. The water in this chamber will consequently flow out through the bottom outlet valve G, its discharge being aided by the forcing action of the entering current of steam and air from the exhauster; and this forcing action may be regulated by closing the top of the delivery funnel of the exhauster, in which case the discharge pipe for the water from the outlet valve G may be raised above the level of the chamber A. As the water descends in the chamber A, the float M sinking with it moves over the tumbling lever N into the vertical position, from which when the chamber is emptied the lever will fall into the reversed position, thereby throwing over the reversing valve L. The action of the exhauster upon the two chambers is now reversed, the air being exhausted from the emptied chamber A, and the combined jet discharged into the chamber B, which during this time has become filled with water; in this way the two chambers become alternately filled and emptied, and a continuous delivery of water is thus obtained. As the steam contained in the combined jet entering either chamber from the exhauster becomes gradually condensed by contact with the water, a partial vacuum will be already formed in the chamber as soon as emptied, whereby the work to be done by the exhauster in then exhausting the chamber will be diminished. In order to prevent the noise which would be caused by the combined jet of steam and air issuing from the open top of the delivery funnel of the exhauster, a "sound killer" S may be placed on the top of the funnel, consisting of a cylindrical metal vessel containing a series of perforated wooden diaphragms; this contrivance has been found by experiment to be very efficient in preventing noise.

The following are the results of a preliminary experiment made with a rough apparatus for raising water, arranged as shown

in the diagram, Fig. 14, Plate 18. The exhauster E was connected by a 2 inch pipe F to a closed vessel A capable of holding 10·3 cubic feet, into which the water was raised from varying depths through the suction pipe D of 2 inches diameter. The sectional area of the outer annular air passage in the exhauster used in this experiment was 0·35 square inch, and of the inner air passage in the centre of the jet 0·16 square inch, giving a total of 0·51 square inch of air section. With the sectional area of the annular steam orifice adjusted to 0·09 square inch, and with a steam pressure of 60 lbs. per square inch in the boiler, the exhauster raised 10·3 cubic feet of water 12 feet high in 40 seconds, and the same quantity $17\frac{1}{2}$ feet high in 75 seconds. With the same area of air section, but with the area of the steam orifice adjusted to 0·08 square inch, and with 50 lbs. steam in the boiler, 10·3 cubic feet of water were raised 15 feet high in 40 seconds. The height of lift attainable depends upon the pressure of steam employed; and the quantity of water raised depends within certain limits upon the magnitude of the jet.

Evaporation of Sugar.—A third application of the improved steam jet is to the Evaporation of Sugar. In consequence of the remarkable results obtained with this steam-jet exhauster, it is proposed by Mr. R. A. Robertson of London to apply it to sugar boiling in the West Indies; and he has communicated to the writer the following notes on the subject.

The steam-jet exhauster has been employed experimentally with considerable success in exhausting vessels for evaporating liquids in vacuo, and its application for this purpose promises to become of great value in the colonies for evaporating cane juice, principally on account of the simplicity of the arrangement. The great loss and deterioration consequent on the high temperature to which cane juice must be exposed for evaporating it on the old system in open pans are well known, and many ingenious pans have been invented and to some extent worked for evaporating at low temperatures; but, on account of the improved pans being either very much more costly or requiring much more skilled attention

to work them, the greater part of the sugar produced is still made on the old and wasteful plan. Of all the contrivances for evaporating at low temperatures the ordinary vacuum pan exhausted by pumps is at present the best, when carefully designed; and in it under favourable circumstances very rapid evaporation can be produced at low temperatures. In the sugar-growing colonies however almost every circumstance is unfavourable for this mode of working; the water required for condensing the vapour from the evaporating pan is warm, and consequently must be used in large quantities, thereby necessitating large pumps for its removal, and for exhausting the pan; the pumps and motive power thus form together with the pan a very costly apparatus, which requires a considerable amount of skilled attention, often not obtainable, and frequent repairs.

On the contrary, a vacuum pan exhausted by the steam-jet exhauster in the manner shown in Figs. 15 and 16, Plate 19, becomes a very simple apparatus, only requiring a supply of steam at a moderate pressure for the jet A, which exhausts the vapour given off by the boiling solution of sugar or other liquid in the pan B; and the steam and vapour together are then passed through the heating tubes D of the pan, thereby producing evaporation. The area of the steam jet is regulated by the hand wheel C, the steam being supplied by the pipe E; and the course of the current of steam and vapour is indicated by the arrows. By this arrangement the costly vacuum pumps and the steam engine or other motive power are dispensed with, as well as the condenser and its supply of condensing water, the latter being in many places a consideration of vital importance; and in their stead is substituted the steam-jet exhauster, a comparatively cheap and simple apparatus, requiring little or no attention, and not liable to get out of order.

Experiments on this mode of evaporating have been so successful that a vacuum pan is now being constructed as above described, capable of evaporating 50 cubic feet of water per hour, in which it is estimated that a vacuum of from 18 to 20 inches of mercury will be maintained. The form of pan shown in Fig. 16 is the simplest arrangement in which the steam-jet exhauster can be applied for

the purpose; but the exhauster can with equal advantage be applied in those cases where vacuum pans are worked on the systems known as double and triple effect. It has been successfully employed to exhaust a vacuum pan having a condenser placed high enough above the ground to discharge by gravitation against the vacuum the condensing water in which the vapour from the pan was condensed; there was thus left only the air and a very small quantity of vapour to be removed by the exhauster, which in this case was a very small one, not using sufficient steam to produce evaporation.

The steam-jet exhauster is further expected, on account of its cheapness and simplicity, to prove very useful in the colonies for draining the molasses from the sugar, by exhausting the air from below the perforated bottom of a strainer containing the undrained sugar, the pressure of the atmosphere then driving the syrup or molasses through the sugar and perforated bottom. By this means the crude and imperfect mode of draining by gravitation, and also the more elaborate but costly and troublesome centrifugal strainers, can be superseded with advantage.

Blower for Gas Producers.—A further application of the improved steam jet is to Gas Producers for heating purposes. The author has had occasion to make numerous applications of the steam jet arranged as a blower for accelerating the distillation of fuel in his gas producers, as shown in Figs. 17 and 18, Plate 20.

The blower B is built into the side wall of the producer, and the combined current of air and steam delivered by it issues through an opening A into the space C underneath the firegrate, which is closed by doors D. The small proportion of steam that enters together with the air is just sufficient to assist beneficially in the production of the combustible gas, inasmuch as in passing through the incandescent fuel the steam becomes converted into hydrogen and carbonic oxide. The steam is admitted to the blower through the branch pipe E from the main steam pipe F, which supplies a number of blowers in a series of gas producers. A valve G is provided in the branch pipe E, for shutting off the steam from the

blower when not in use; and a small tap J serves for discharging any water that may collect in the pipe by condensation of the steam.

The advantages found to result from applying these blowers to gas producers are, that coal dust of the most inferior description can be used, and that the gas production of each producer in consuming small fuel is raised from $1\frac{1}{2}$ tons to 3 tons of gas per 24 hours; while at the same time the quality of the gas is improved, owing to the generation of hydrogen from the steam which enters intermingled with the air.

These applications of the improved steam jet suffice to illustrate its scope and value. Other useful applications will readily suggest themselves, where work may be accomplished by exhausting or compressing air or gases.

In conclusion the author would remark that although the steam jet is not a new mechanical agent, and has been applied before for various purposes and in a variety of forms, yet the mechanical conditions under which it is capable of developing the greatest amount of useful effect have not previously been laid down or practically realised in such a way as to produce results at all comparable with those obtained from a steam engine working an air pump; but this it is maintained a steam jet may do, if care be taken that the available elastic force is changed into onward motion of the combined jet, and again into onward pressure, without undue loss of effect by eddies or by development of sound or heat, which have constituted the principal results in the case of an ordinary steam jet.

The PRESIDENT said he had been led to investigate the subject of the steam jet in consequence of having been engaged in constructing a circuit of pneumatic despatch tube for the Central telegraph office in London; the tube itself had cost £3000, and fully as much had

been spent on the engine and air pump. As there was moreover great difficulty in finding room for this machinery in so crowded a locality, it had occurred to him that a more direct means of propelling the piston carriers through the tube would be a matter of some importance; and in considering the conditions of a steam jet he had been led to the conclusion that, if the elastic force of the steam could be all employed for giving velocity to its particles, and if each particle of steam so accelerated could be brought into direct and immediate contact with the air to be impelled, an average speed of the combined current could be obtained, which should represent nearly the whole of the elastic force originally existing in the steam. If this combined current were then sent through a long expanding mouthpiece or tube, enlarging gradually in a parabolic curve, so that the velocity of the current should be gradually converted into pressure by bringing the particles nearly to rest, it had appeared to him that very favourable results might be obtained; and the experiments he had made had proved that these anticipations had been correct.

There were some remarkable results connected with this steam jet. The quantity of work done by it, measured by the weight of air delivered per minute, was proportionate absolutely to the amount of surface contact between the steam jet and the air to be impelled, irrespective of the pressure of steam employed. Thus in discharging the combined current into the atmosphere, the same weight of air per minute would be thrown out with a steam pressure of 5 lbs. as with 60 lbs., the only difference being that with the lower pressure of steam the limit of exhaustion or compression would be sooner reached than with the higher. The experiments also showed that the degree of exhaustion or compression capable of being produced by the steam jet, that is the difference of pressure between the air at the jet and that in the vessel from which the jet was exhausting or into which it was compressing the air, was exactly proportionate to the steam pressure; so that with 100 lbs. steam above the atmosphere the degree of exhaustion or compression attainable was double what it was with 50 lbs. steam. A third result was that, in exhausting the

air from any vessel by the steam jet, it took as long a period of time to exhaust the first 1 lb. of pressure, from the atmospheric pressure of say 15 lbs. down to 14 lbs., as it did to reduce the pressure 1 lb. in any lower part of the scale, say from 8 lbs. to 7 lbs.; this was explained by the consideration that the weight of air, which had to be put into motion with such a velocity as would force it through the contracted opening at the base of the expanding delivery tube, was the measure of the working capacity of the instrument. These were very distinctly marked characteristics of a good steam jet; and if they were attended to in the construction of the jet apparatus for any particular application, it would be found that very economical results could be realised for the steam expended.

He exhibited a full-size specimen of one of the steam-jet exhausters employed to exhaust the pneumatic tube connecting the telegraph offices in London, so as to maintain a current of air flowing continuously through the tube in the same direction. The tube formed a complete circuit, and the piston carriers, whether put in at the commencing station of the circuit or at any intermediate station, all travelled in the same direction; the result was that a tube of only 3 inches diameter was sufficient for a great amount of work, because there might be ten or more carriers in the tube at a time, all flowing towards the end station, but capable of being intercepted and taken out at any intermediate station.

Mr. L. Olrick enquired whether in the use of the steam jet the parabolic form of the delivery tube was found to make much difference in the efficiency of the instrument, in comparison with a parallel tube or an ordinary cone with straight sides. He understood that in the early experiments upon the ejector condenser the expanding discharge tube for the delivery of the water had been found to produce a greatly increased effect, as compared with the parallel tube originally tried. He asked also whether the mixing chamber in the steam-jet apparatus was shaped to the form of the "vena contracta," from the orifice of the jet to the base of the delivery tube; and what difference was produced by the shape of the air entrance, according as it

was tapered before reaching the jet orifice or made parallel right up to the jet. It appeared to him that this improved steam jet would be applicable to a variety of purposes, and that one application might be to the blast-pipe in locomotives. On some railways the locomotives were made with conical chimneys expanding upwards, which he understood were found to render the blast more effective, and cause less back pressure in the cylinders, than was the case with the usual parallel chimneys; and he thought that the efficiency of ordinary boilers, where the exhaust steam was used as a blast for creating a draught, might be very materially increased, and a saving of fuel effected, with scarcely any back pressure in the cylinders, if due attention were paid to the results derived from the careful experiments which had been made in connection with the very perfect steam jet now described.

The President replied that the expanding form of the delivery tube from the steam jet was of considerable importance, though not so much so in the case of air as where a denser fluid had to be dealt with, as in the water jet of the Giffard injector. From experiments that he had made with a parallel delivery tube, in comparison with the expanding form, he had found that, in exhausting a vessel to the extent of producing a vacuum of 20 inches of mercury, the expanding tube rendered the jet about ten per cent. more effective than it was with the parallel tube; but in exhausting to only a small extent, the greater density of the fluid would cause the expanding tube to be as much as twenty per cent. more effective than a parallel one. The form which he had adopted for the expanding delivery tube of the steam jet was a parabolic curve; but the difference in effect between this and an ordinary straight cone, with the same areas of passage at the two extremities, would be immaterial. The mixing chamber, which had to be of a definite length in proportion to the breadth of the annular air passage, was made to diminish gradually in area, somewhat in the form of a "vena contracta," the rate and extent of contraction being determined in each individual case according to the velocity of the combined issuing current. But the point of chief importance in the instrument was the mode of bringing the entering air into

contact with the steam jet. As the working power of the jet was proportionate to the extent of surface contact between the steam and the air, the annular form of jet suggested itself as the most suitable; and the thickness of the annular film of steam should be very small, about 1-50th inch having been found by experiment to be the maximum thickness of film that was consistent with economical results. If the thickness of the jet were increased beyond this amount, the particles of steam inside the thickness of the jet would flow on at a greater rate than the outer particles forming the skin of the jet, the latter being retarded by contact with the air; and eddies within the atmosphere of the steam itself would be the result. Again, if the steam jet were simply made to issue into a plain open tube, through which the air had to be propelled, the result would be very inconsiderable, because the eddies formed between the air and the steam would then attain their maximum amount; the steam issuing with great velocity and the air being nearly stationary, the latter would not be so much impelled in a steady current as set in rotation and rolled forwards by the power represented by the difference of velocity between the two fluids. It was consequently requisite that the air should be accelerated as nearly to the full velocity as practicable before coming into actual contact with the steam; and this was the most important point connected with the apparatus. The area of the air passages was therefore gradually contracted for some distance as they approached the issuing orifices; and the combined areas of the central air aperture inside the steam jet and of the annular aperture outside the jet were made to be together rather less than the area of the issuing orifice at the outer extremity of the mixing chamber, through which the combined current issued; this arrangement ensured the air attaining the full velocity of the combined jet, whereby the amount of eddies and the consequent loss of power were reduced to a minimum.

Mr. J. B. Fenby enquired what had been found to be the relative expenditure of steam in the jet, when employed in producing a vacuum, for effecting an equal reduction in the pressure of the air at different degrees of vacuum. The length of time required to

reduce the pressure 1 lb. had been stated to be the same, whether the reduction were from 15 to 14 lbs. or from 8 to 7 lbs.; but it appeared to him that the amount of work done in the latter case would be greater than in the former, because with the greater vacuum in the exhausted vessel the same weight of air had to be discharged against the greater excess of pressure of the external atmosphere: just as, in the case of an engine working an air pump, the load on the engine would increase in proportion to the degree of vacuum already produced by the pump. One application that occurred to him, for which the steam jet would probably be advantageous, was the air blast for millstones, for removing the stive or dust from the casing of the stones during the grinding. From the small space occupied by the instrument, and the great velocity produced in the current of air, it seemed to him likely to be well suited for that purpose, particularly if employed for exhausting the air, its efficiency being greater in exhausting than in compressing; and he thought it would probably be more suitable than the blowing fan used for ventilating millstones.

The PRESIDENT replied that that application of the steam jet might be attended with good results; but it must be observed that the jet acted at a disadvantage when producing only a small degree of exhaustion or compression, though this disadvantage might to a certain extent be obviated by reducing the area of the jet orifice when the work was below the capabilities of the full jet. For as the surface of contact between the steam and air determined the work done, and the quantity of steam of a given pressure in the jet in proportion to the air determined the degree of vacuum or compression produced, it followed that, in order to work economically, the area of the steam orifice ought to increase gradually as the vacuum or compression increased. Under any circumstances however the jet would be to some extent less advantageous when producing only a small degree of vacuum, because the difference of velocity between the steam and the air, which was productive of eddies, was then greater than when an equal weight of air was discharged from a higher degree of vacuum, a larger proportion of the velocity of the steam being utilised in the latter case for

overcoming the greater excess of pressure of the external atmosphere. The steam jet had not yet been applied for producing the air blast for millstones, but no doubt it might be employed advantageously for that purpose.

Mr. J. Robinson, who occupied the Chair during the discussion of the President's paper, remarked that several attempts had previously been made to take advantage of the induced currents created by a steam jet. In the early application of the blast pipe in locomotive engines, when the blast had not been sufficiently effective in producing the draught required for the fire, he remembered one improvement introduced had been what was known as the "petticoat" blast pipe, consisting of a succession of cones arranged one above another with a set of concurrent lateral openings between, the object being to equalise the force of the draught throughout the height of the smokebox, instead of producing a strong draught through the upper tubes and a weak one through the bottom tubes, as was the case when the blast pipe was carried up solid to the top of the smokebox, causing the steam jet to act upon the air only at that point; the larger area of the improved blast pipe had also occasioned a diminution of the back pressure in the cylinders. A similar improvement had been tried on the Giffard injector, by inserting a number of conical nozzles, one behind another, so that a smaller quantity of water should be brought into contact with the jet at each successive step, instead of the steam jet having to encounter all the water at once, the effect of the cones thus being to increase the extent of surface contact between the steam and water. A jet of steam had also been applied for inducing a current of air as a blast for cupolas employed for melting iron; instead of forcing the air into the bottom of the cupola by a blowing fan, the closed top of the cupola was exhausted by a steam jet in the chimney, by which means the air was drawn in uniformly through openings made all round the bottom of the cupola. With regard to the application of the steam jet for raising water, the method described in the paper presented a marked contrast to that attempted in Giffard's first trials for the purpose, where the steam had simply been turned direct into the stationary water at the bottom of the ascending pipe through

which it had to be raised; and in consequence of the inertia of the water and the fact that the whole mass of water had to be started into motion at the jet, there had necessarily been a great loss of effect by the production of eddies, instead of an even flow. The plan now described seemed much the more philosophical and advantageous, in which the steam jet was not brought to bear direct upon the water, but was applied to exhaust the air from a closed vessel, and the water was then raised into the vessel by the pressure of the external atmosphere; because the steam would more readily carry off the air from such a vessel into the atmosphere than it would put into motion a column of water, the inertia of the water being so greatly in excess of that of air. One valuable application of the steam jet that occurred to him would be to the ventilation of the cabins and stoke-holes of ships, particularly in the case of ironclads, where the admission of air was rendered so much more difficult by the absence of openings in the sides of the ship. It had indeed been attempted to use a blowing fan for introducing a supply of fresh air in such cases; but he considered a much better plan would be to exhaust the bad air, and leave the fresh air to find its way in wherever it could; and for this purpose the steam-jet apparatus now described appeared most suitable, and he should be very glad to hear of its being so applied. There were also without doubt many other directions in which the improved steam jet might be usefully employed with advantage.

He moved a vote of thanks to the President for his paper, which was passed.

The Meeting then terminated.

Compound Stationary Engines

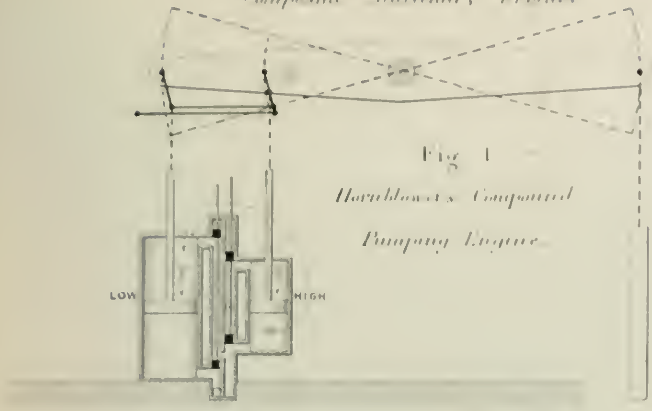


Fig. 1
Hornblower's Compound Pumping Engine.

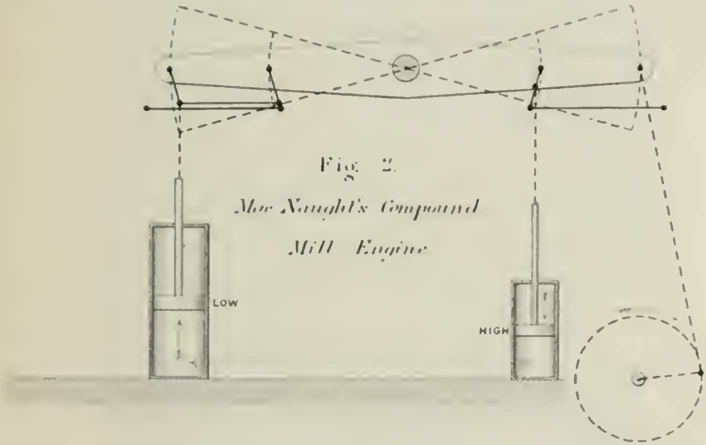


Fig. 2.
MacNaught's Compound Mill Engine.

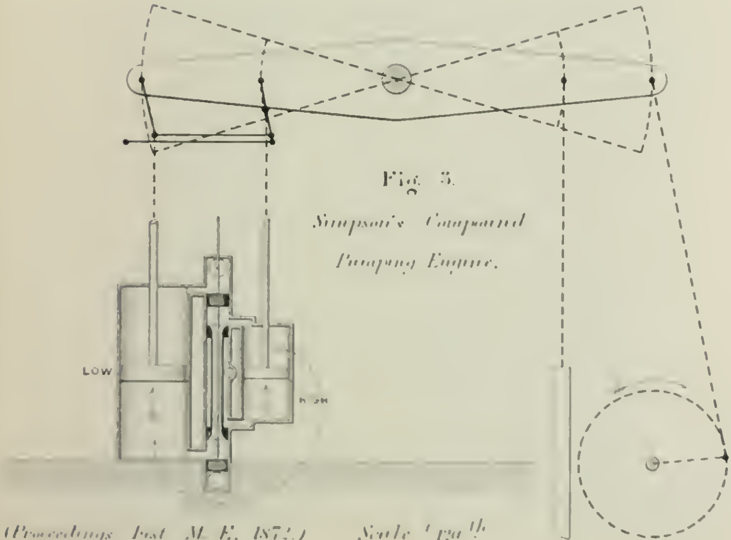


Fig. 3.
Simpson's Compound Pumping Engine.

(Proceedings Inst. M. E. 1872.) *Scale 1/120th*

Compound Paddlewheel Engine with two pairs of inclined Cylinders working two opposite cranks

Fig. 4. *Transverse Section at High-pressure Cylinders*

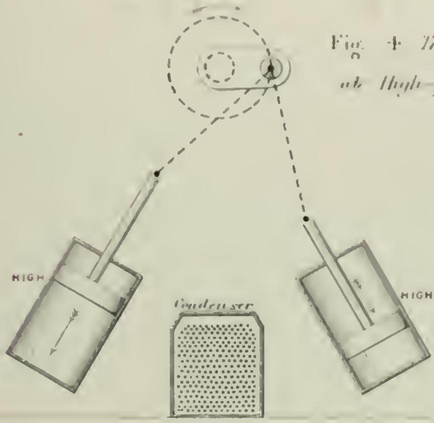


Fig. 5. *Transverse Section at Low-pressure Cylinders.*

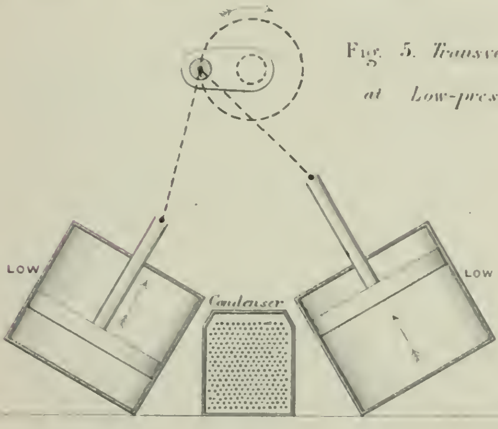
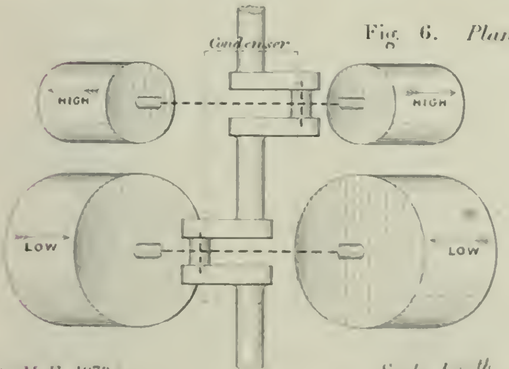


Fig. 6. *Plan.*



Scale 1/60th

0 5 10 15 *Feet.*

MARINE ENGINES.

Plate 23.

Compound Screw Engine with two pairs of cylinders, working two pairs of opposite cranks.

Fig. 7. Longitudinal Section

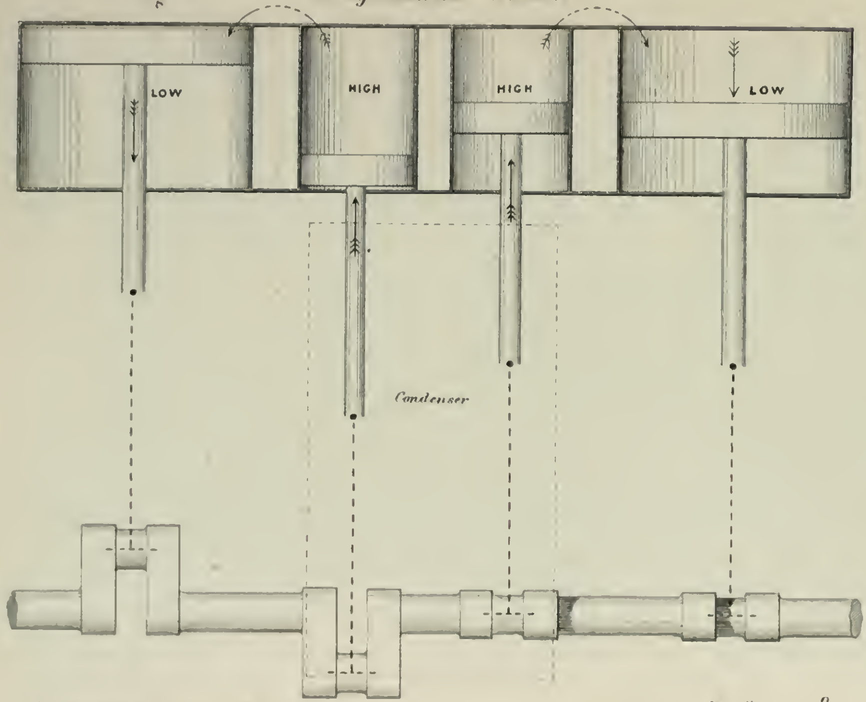
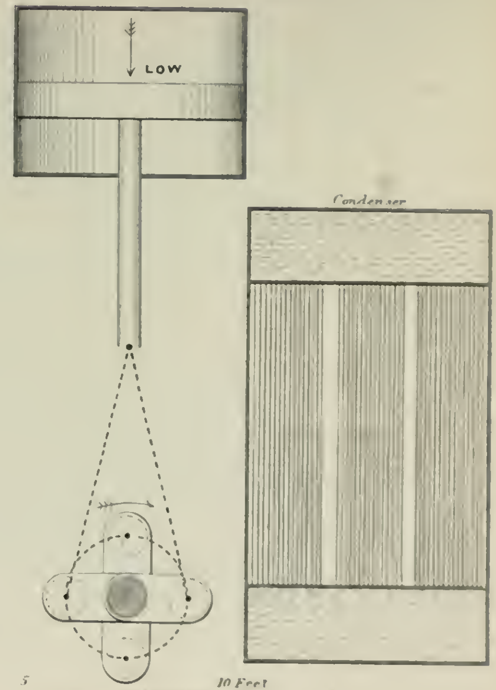


Fig. 8. Transverse Section



(Proceedings Inst M E 1872)

Scale $^1/_{60}$th 0 5 10 Feet

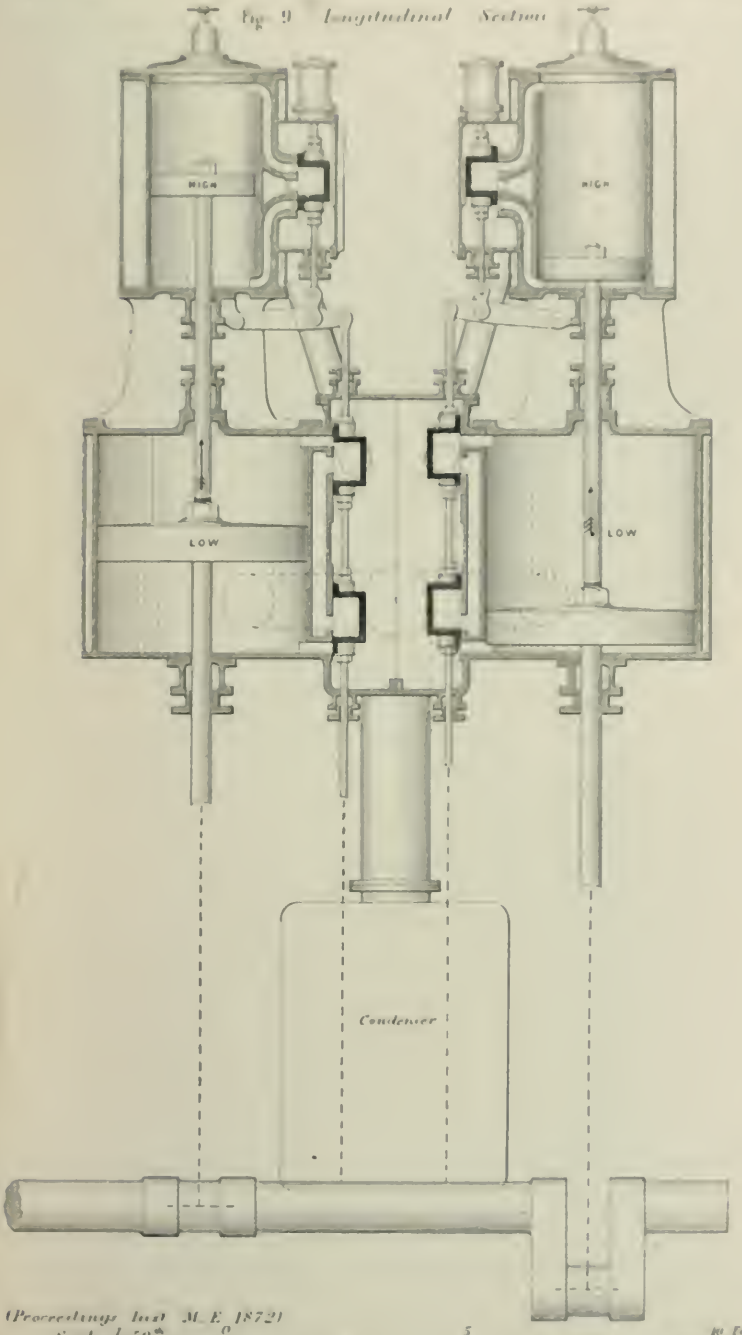
MARINE ENGINES

Plate 24

Compound Screw Engine with two pairs of combined cylinders, working two cranks at right angles

High pressure cylinders added on top of Low pressure cylinders

Fig. 9 Longitudinal Section



(Proceedings Inst. M. E. 1872)

Scale 1/30th 0 5 10 Feet


Pi

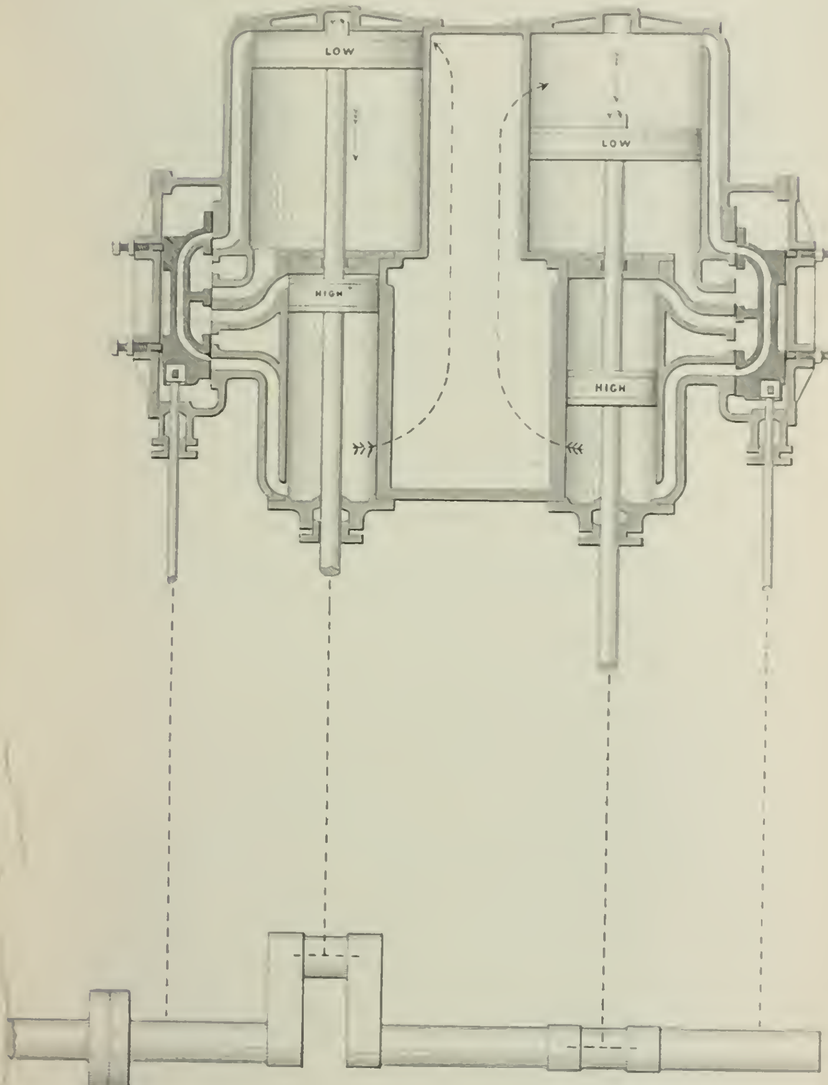
MARINE ENGINES

Plate 27.

Compound Screw Engine with two pairs of combined cylinders, working two cranks at right angles

Low above High-pressure cylinders combined in one casting

Fig. 10. *Longitudinal Section*



(Proceedings Inst. M. E. 1872.)

Scale 1/50th

Ins 12 6 0 1 2 3 4 5 6 7 8 Feet

MARINE ENGINES

Compound Screw Engine with two pairs of combined cylinders, working two cranks at right angles

Low pressure cylinders annular

Fig 11. *Vertical Section*

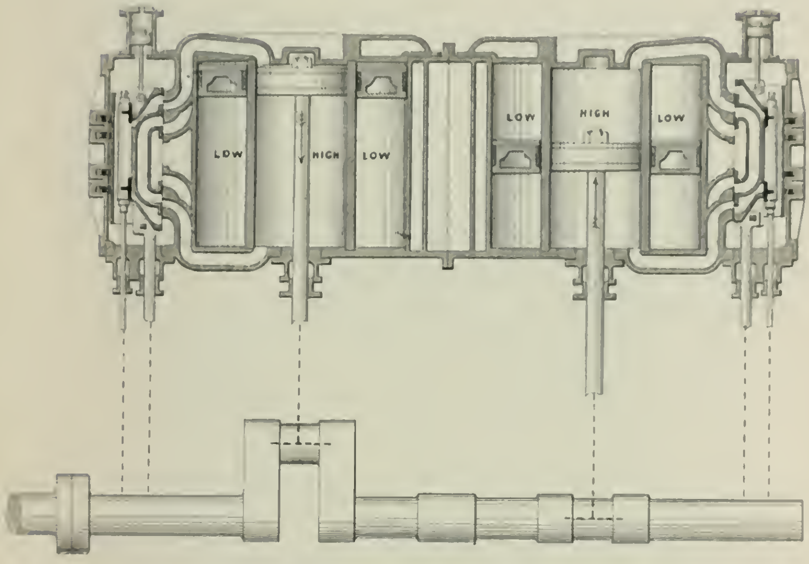
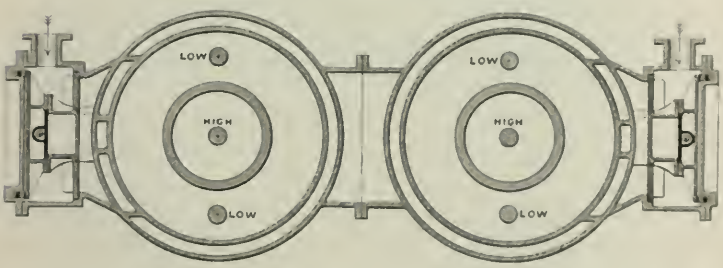


Fig. 12. *Sectional Plan.*



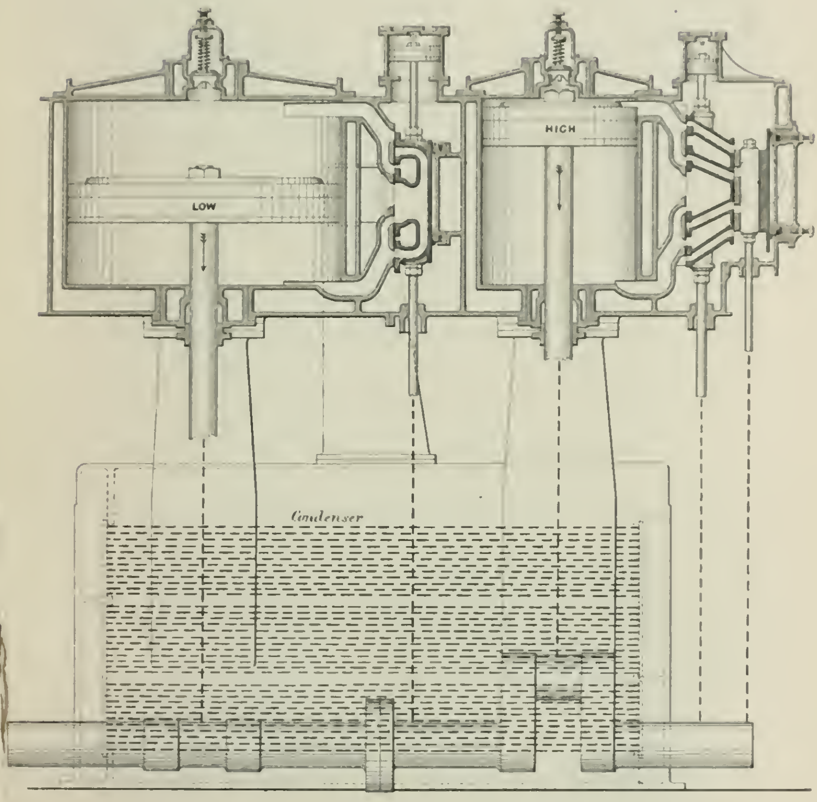
(Proceedings Inst. M. E. 1872)

Scale $1/50^{th}$

0 5 10 Feet

Compound Screw Engine with one pair of cylinders, working two cranks at right angles.

Fig. 13. *Longitudinal Section.*



(Proceedings Inst M. E. 1872.)

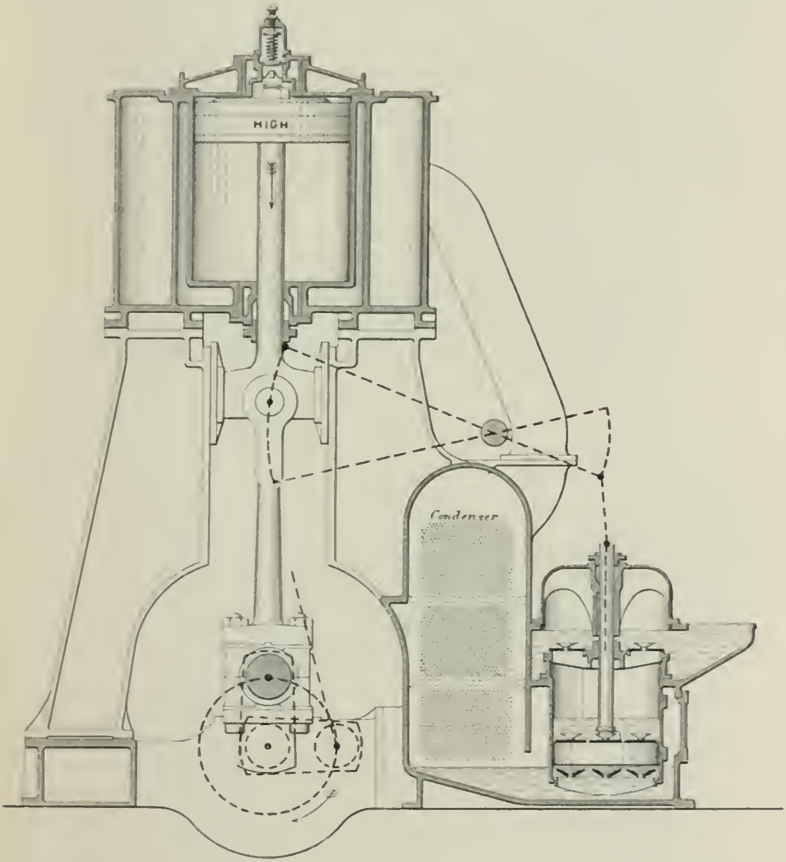
Scale 1/60th

0 5 10 15 *Feet*

Compound Screw Engine with one pair of cylinders,

working two cranks at right angles.

Fig. 14. *Transverse Section.*

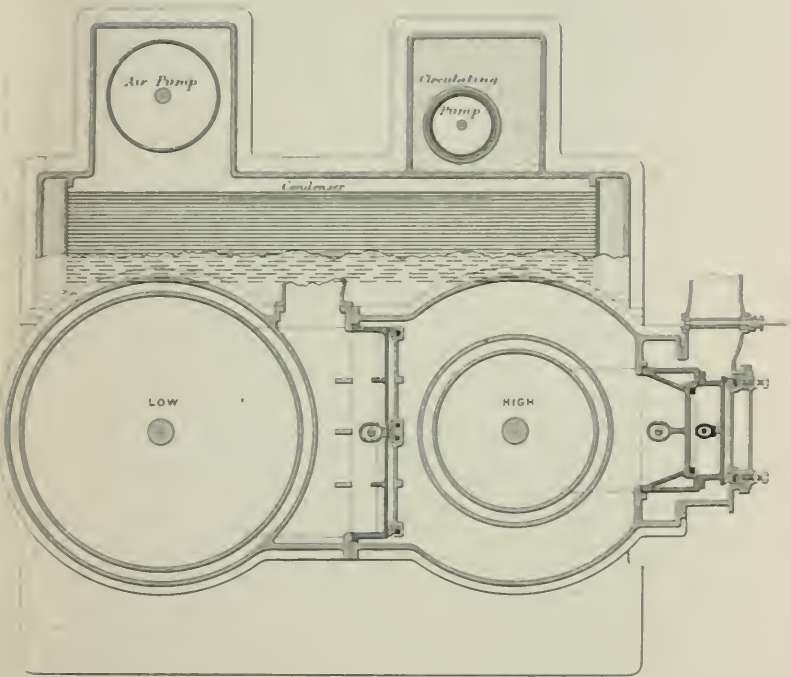


Scale 1/60th

0 5 10 15 Feet

Compound Screw Engine with one pair of cylinders, working two cranks at right angles.

Fig. 15. *Sectional Plan*



(Proceedings Inst. M. E. 1872.)

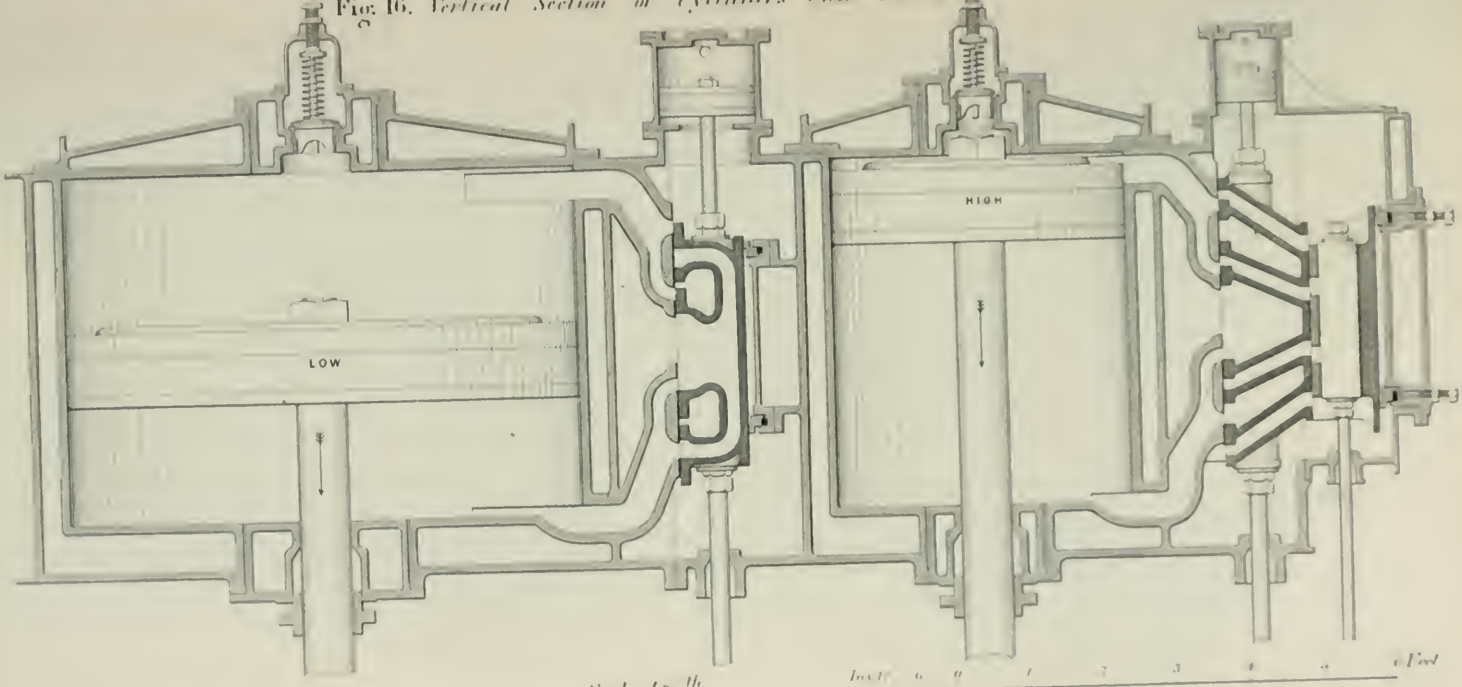
Scale 1/60 th

0 5 10 15 Feet

MARINE ENGINES.

Compound Screw Engine with one pair of cylinders, working two cranks at right angles.

Fig. 16. *Vertical Section of Cylinders and Valves.*



Scale 1/30th

Diagrams illustrating action of steam in ordinary Compound Engines with one pair of cylinders working two cranks at right angles

Fig 17.

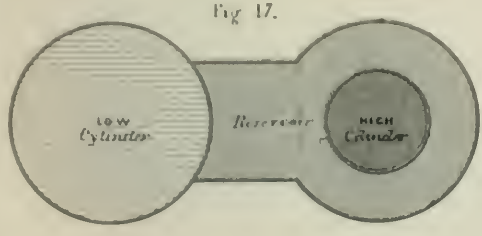


Fig 23

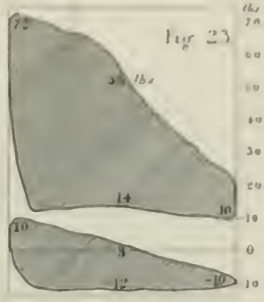


Fig 18.

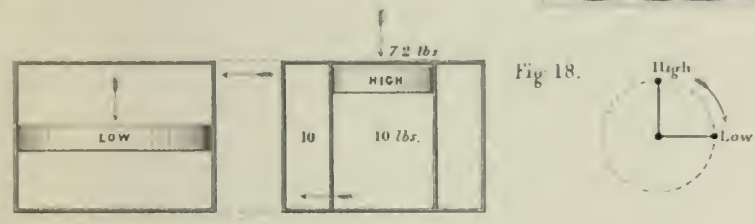


Fig. 19.

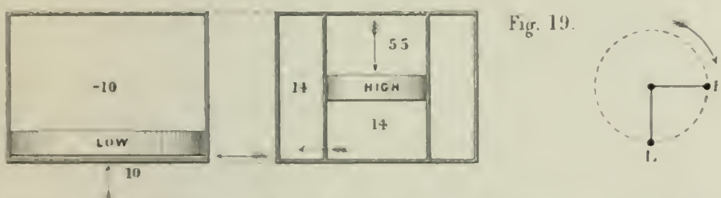


Fig. 20.

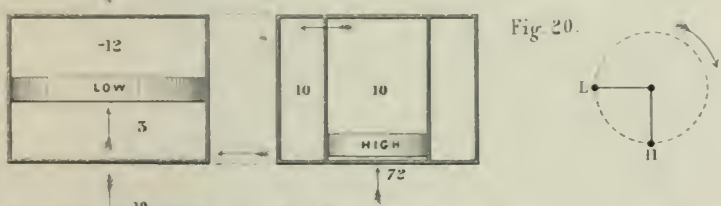


Fig. 21.

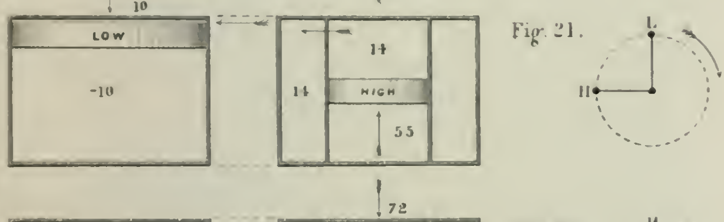
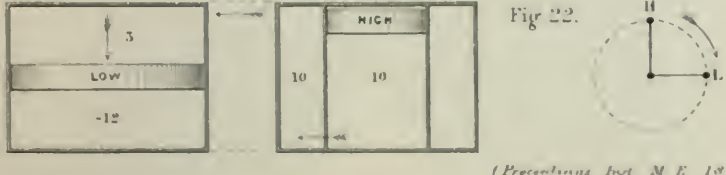


Fig 22.

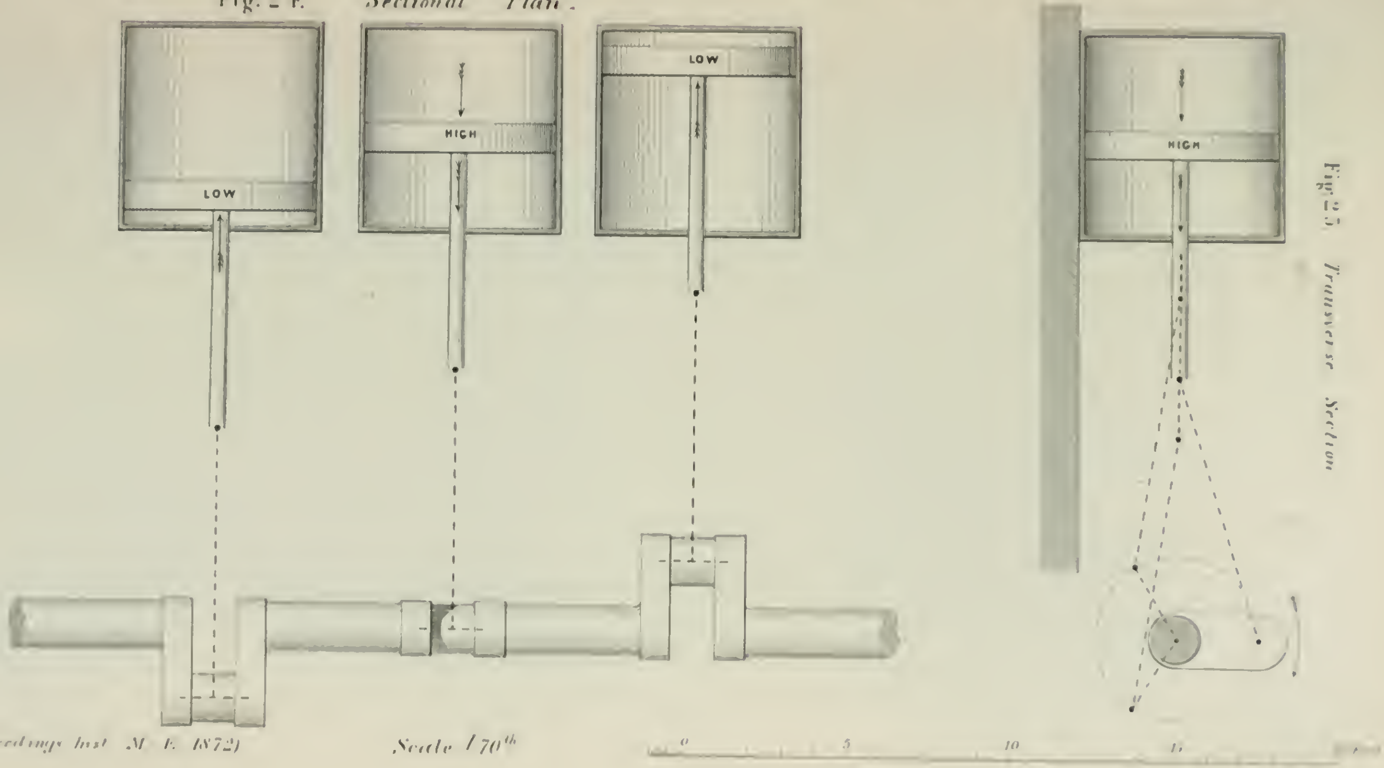


MARINE ENGINES

Compound Screw Engine with three cylinders, working three cranks at equal angles

Fig: 24. *Sectional Plan.*

Fig: 25. *Transverse Section*



(Proceedings Inst. M. E. 1872) *Scale 1/70th*

MARINE ENGINES.

Plate 33.

Low - Pressure
Old Flat - Flue Boiler.

Fig. 26.

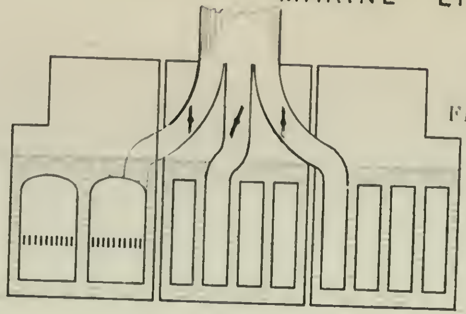


Fig. 27.

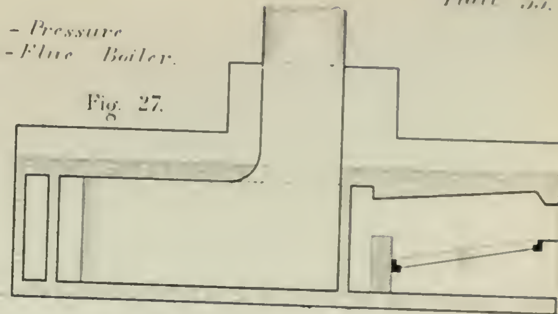
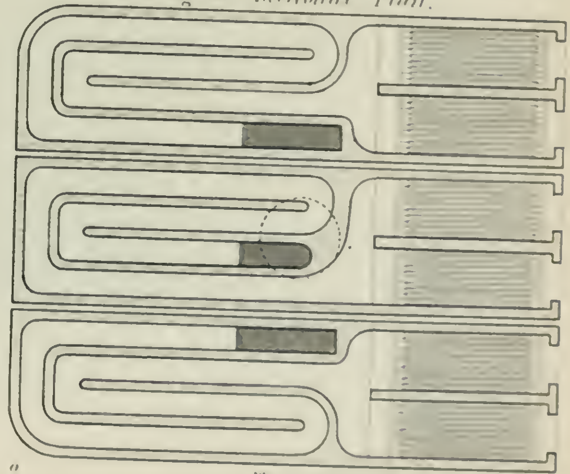


Fig. 28. Sectional Plan.



Low - Pressure
Modern Tubular Boiler.

Fig. 29.

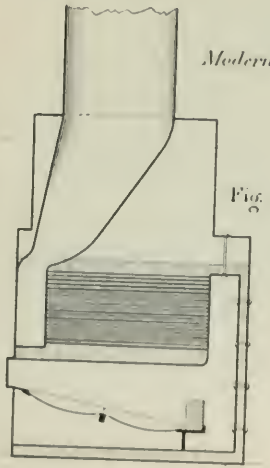
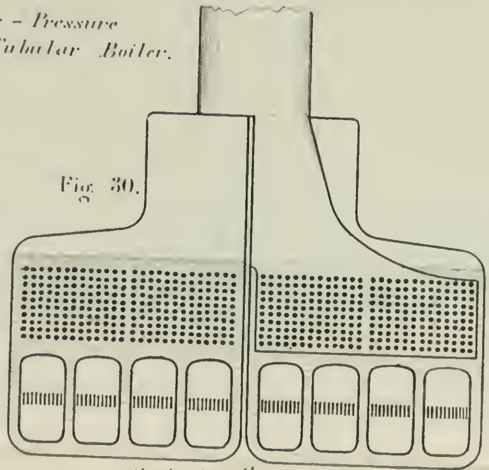


Fig. 30.



(Proceedings Inst. M. E. 1872.)

Scale 1/100th

10 5 0 10 20 Feet.

MARINE ENGINES.

High-Pressure Marine Boiler.

Fig. 31. *Transverse Section.*

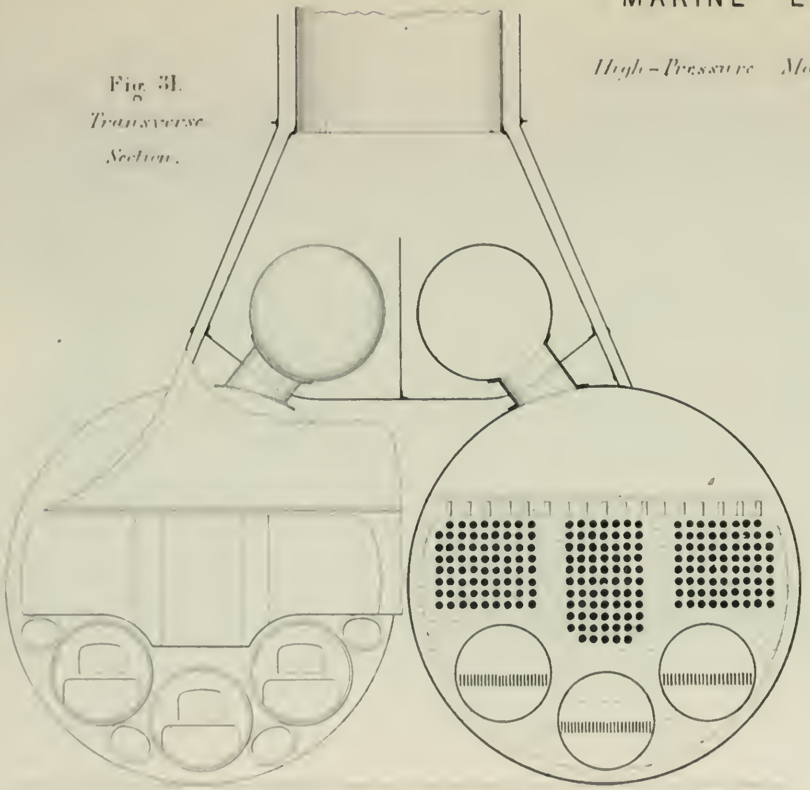
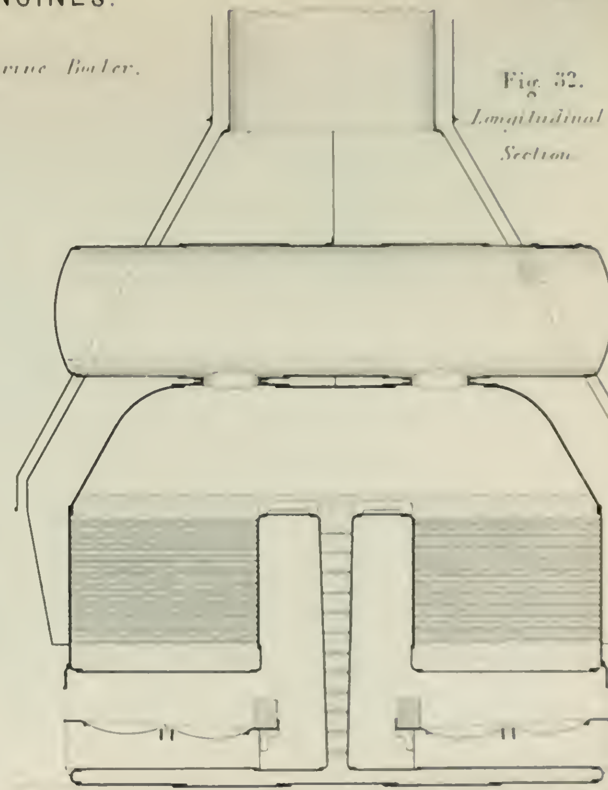


Fig. 32. *Longitudinal Section.*



Scale 1/80th

0 5 10 15 20 feet

(Proceedings Inst. M. E. 1872.)

MARINE ENGINES.

Diagrams illustrating Variation of Tangential Force.

Steam full on to end of stroke.

Fig. 33. *Indicator Diagram.*

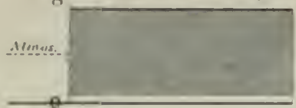


Fig. 34. *Variation with One cyl.*

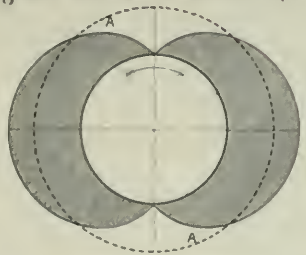


Fig. 35. *Variation with Two cyls. working cranks at right angles.*

Steam cut off at half stroke.

Fig. 36. *Indicator Diagram.*

Fig. 37. *Variation with One cyl.*

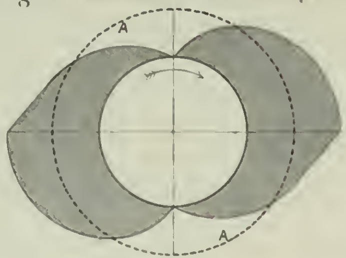
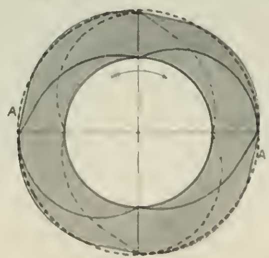


Fig. 38. *Variation with Two cyls. working cranks at right angles.*



Compound Engine of "Spain"

Fig. 39. *Indicator Diagram from Fig 41. Plate 36.*

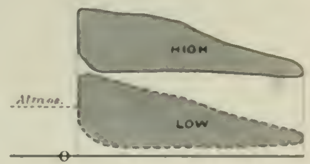
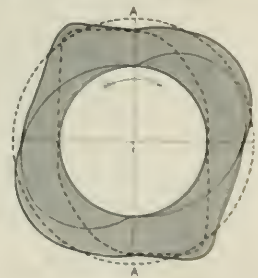


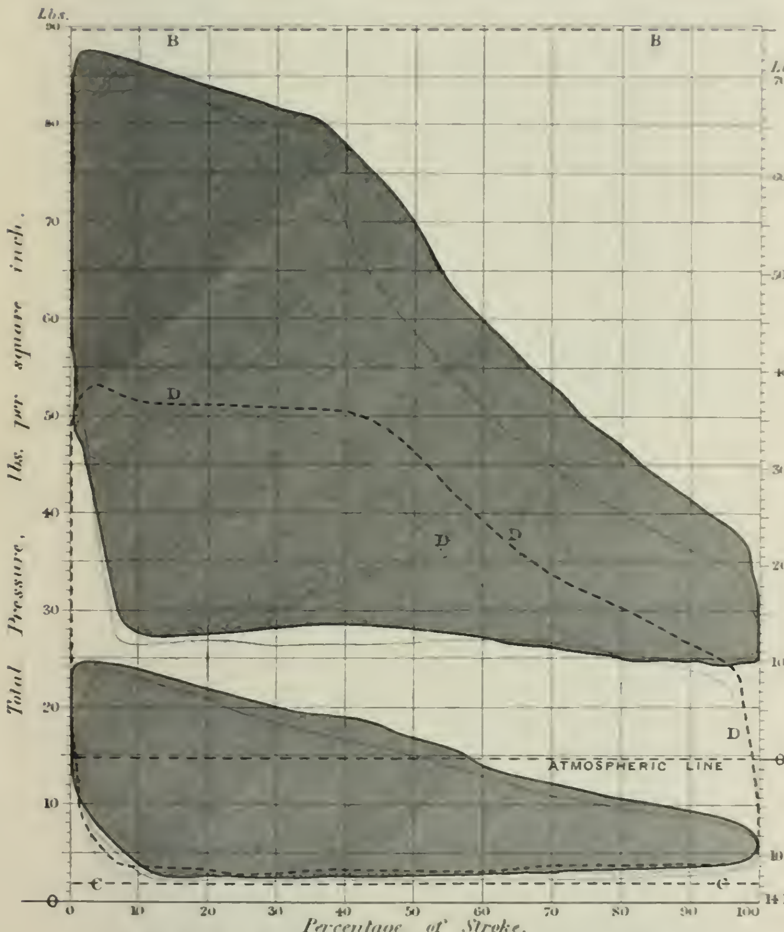
Fig. 40. *Actual Variation in Compound Engine with a pair of cylinders working cranks at right angles.*



(Proceedings Inst. M. E. 1872.)

Fig. 41. *Indicator Diagrams from Compound Engine of "Spain" with one pair of cylinders working cranks at right angles.*

52 *revs. per min.* $4\frac{1}{2}$ *ft stroke.*
60 *and* 106 *ins. diam. cylinders.*
35·9 „ 12·8 *lbs. mean pressure.*
1441 „ 1602 *H. P.* *Total* 3043



B B *Boiler Pressure.* C C *Condenser Vacuum.*

D D *Indicator Diagrams from high-pressure cylinder worked as a single condensing engine, when low-pressure cylinder was disabled.*
35 *revs. per min.* $4\frac{1}{2}$ *ft. stroke.* 60 *ins. diam. cylinder.*
36·4 *lbs. mean pressure.* 982 *H. P.*

(Proceedings Inst. M. E. 1872.)

Fig 42 *Combined Indicator Diagram constructed from Fig 41, from Compound Engine of Spain*
Cylinders 60 *and* 106 *ins diam and* 4½ *ft stroke working cranks at right angles.*

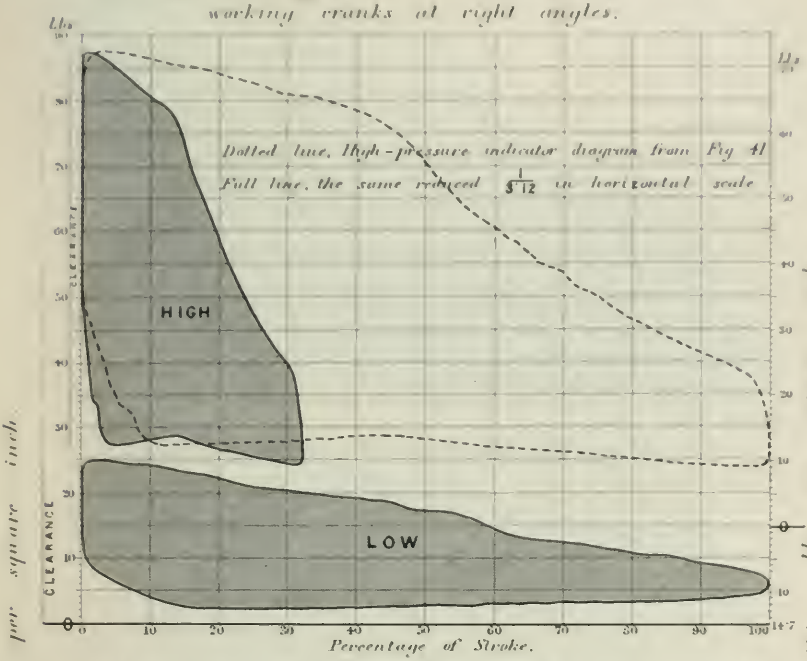
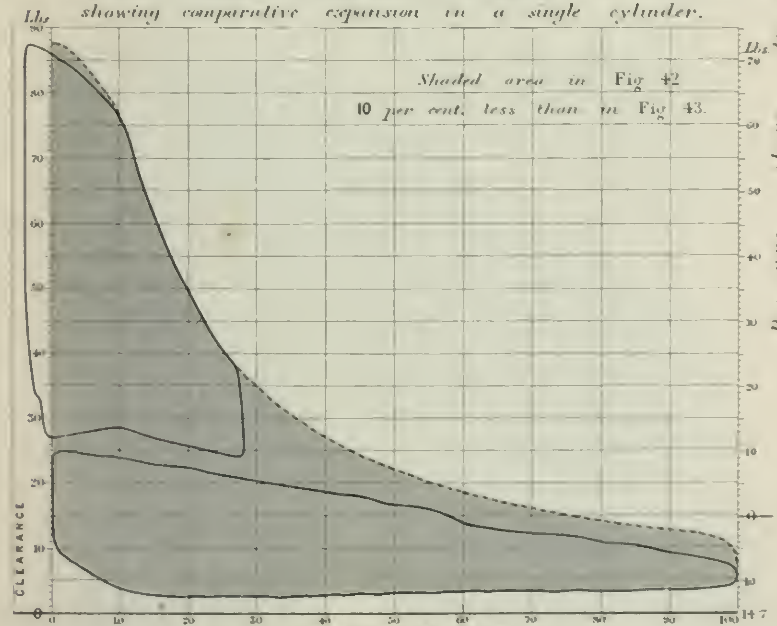


Fig 43. *Indicator Diagram constructed from Fig. 42, showing comparative expansion in a single cylinder.*



(Proceedings Inst M. E. 1872.)

Fig 44. *Indicator Diagrams from Compound Engine shown in Fig. 13, with one pair of cylinders working cranks at right angles.*

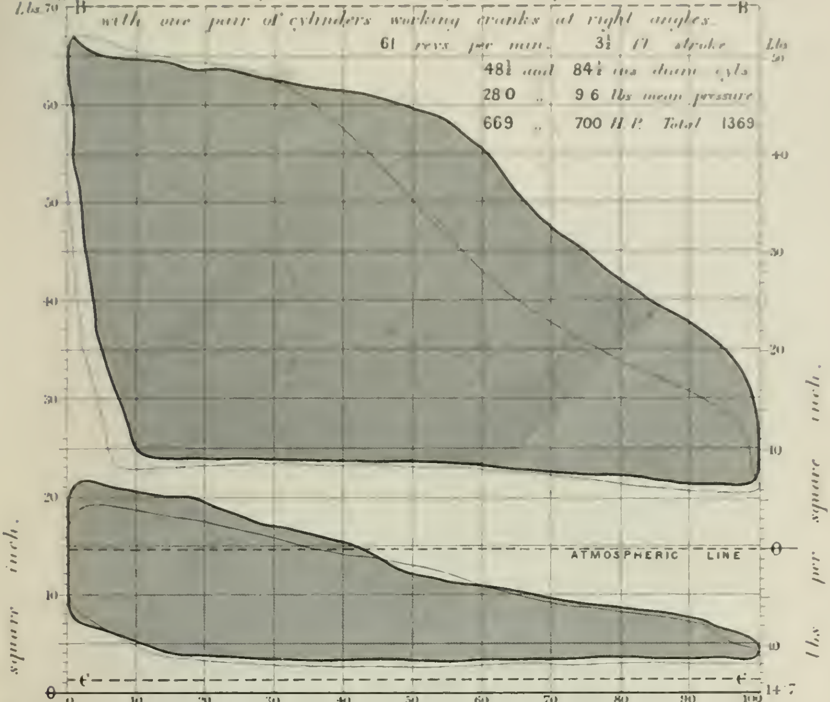
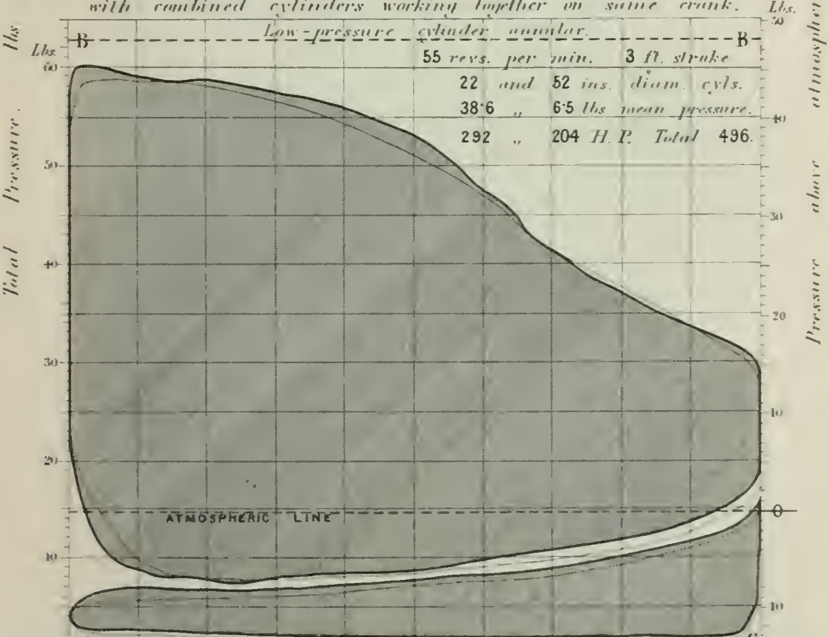


Fig. 45. *Indicator Diagrams from Compound Engine shown in Fig. 11, with combined cylinders working together on same crank. Low-pressure cylinder annular.*



(Proceedings Inst. M. E. 1872.) BB *Boiler Pressure.* CC *Condenser Vacuum.*

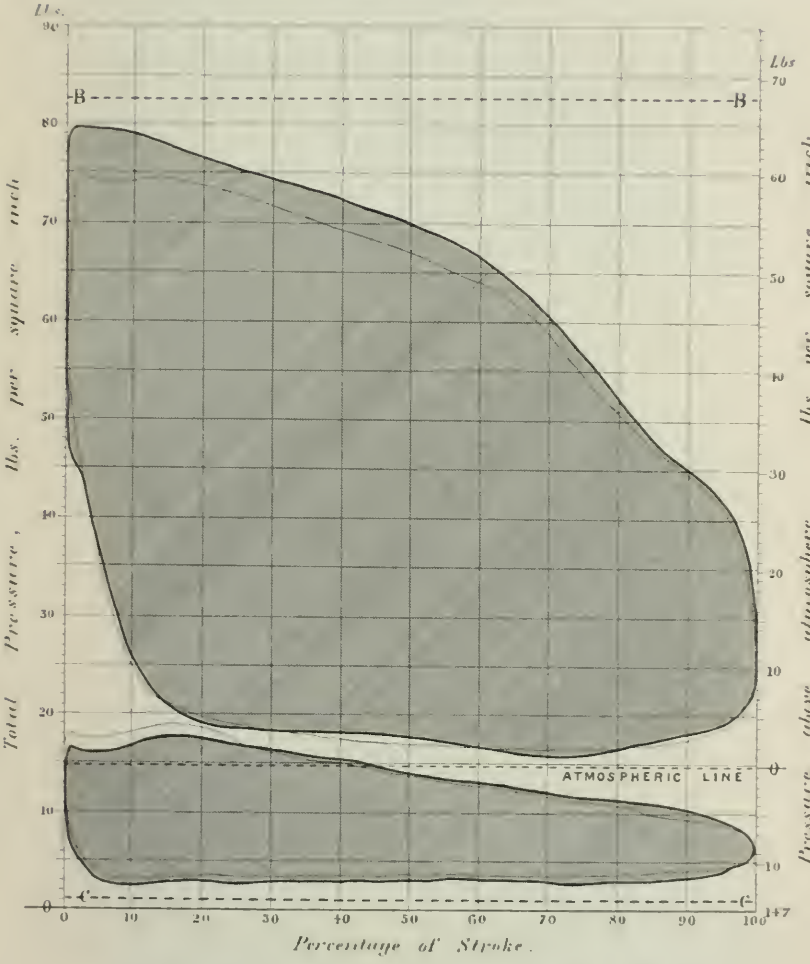
Fig. 16 Indicator Diagrams from Compound Engine with one pair of cylinders working cranks at 135°

66 *revs per min* 2½ *ft stroke*

34 *and* 68 *ins. diam cylinders.*

45·3 .. 10·3 *lbs mean pressure.*

406 .. 373 *H P. Total* 779



B B *Boiler Pressure.* C C *Condenser Vacuum.*

(Proceedings Inst M E, 1872)

Fig. 47. *Indicator Diagrams from Compound Engine with one pair of cylinders working cranks at right angles, replacing original single engines indicated in Fig 48*

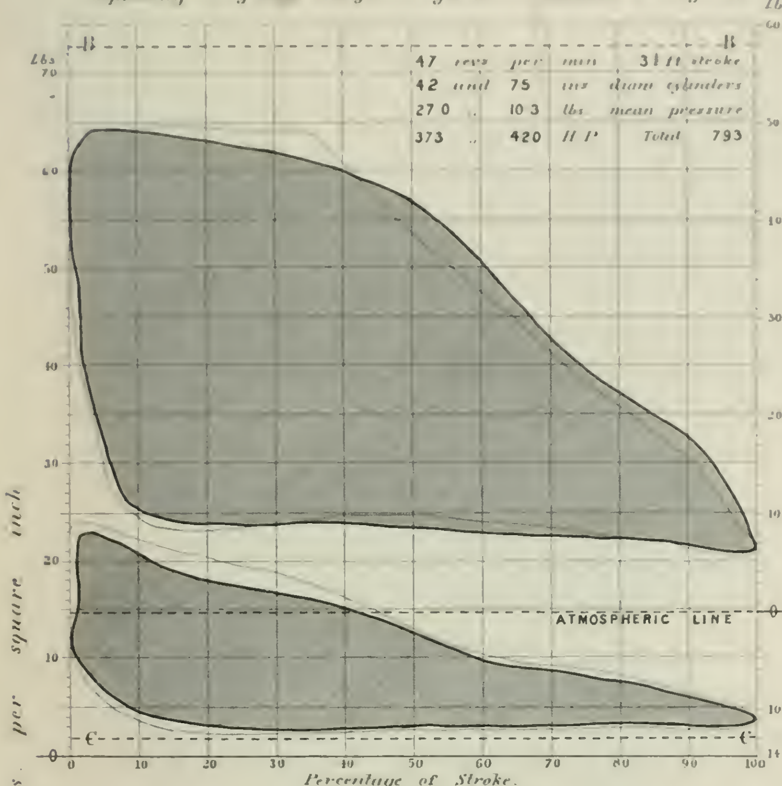
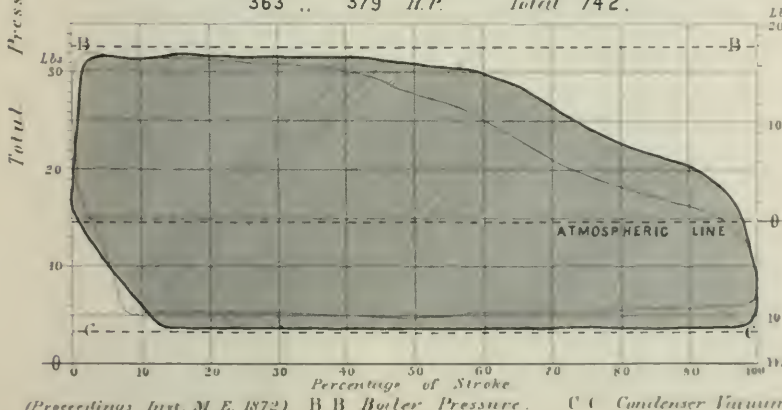


Fig. 48. *Indicator Diagrams from original Single engines replaced by compound engine indicated in Fig. 47.*

41 *revs per min* 3½ *ft stroke.*
54 *and* 54 *ins diam. cylinders.*
19·8 „ 20·6 *lbs mean pressure.*
363 .. 379 *H.P. Total* 742.



(Proceedings Inst. M. E. 1872) B B *Boiler Pressure.* C C *Condenser Vacuum*

MARINE ENGINES.

Plate 41

Indicator Diagrams from Compound Engine of "Briton" with one pair of cylinders working cranks at right angles

Fig. 49. *Speed* 13 *knots per hour.*

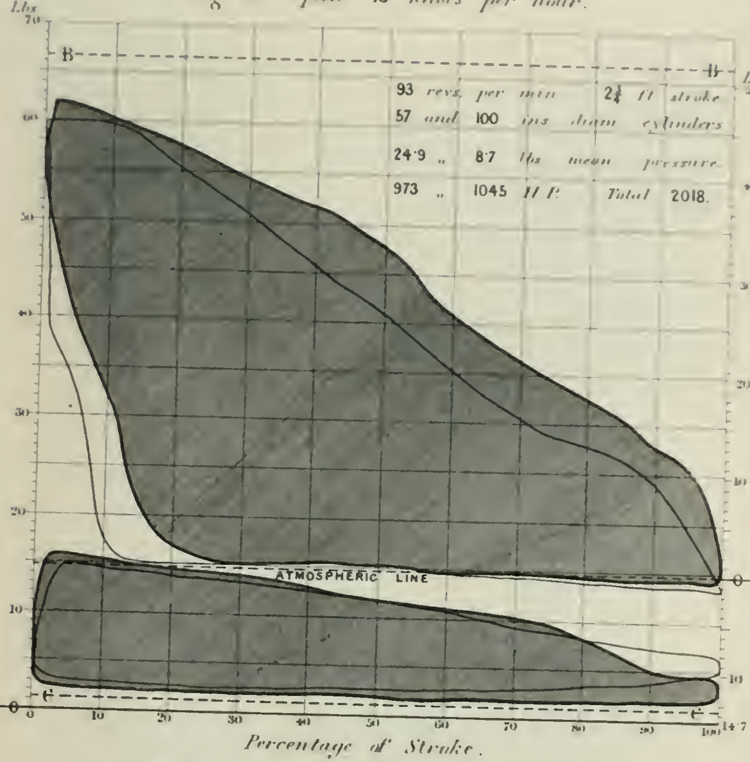
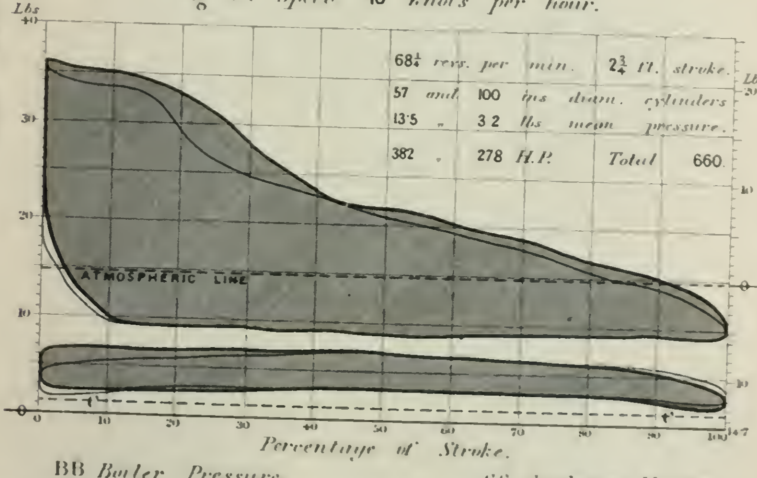


Fig. 50. *Speed* 10 *knots per hour.*



BB *Boiler Pressure.* CC *Condenser Vacuum.*

(Proceedings Inst. M. E. 1872.)

Diagrams illustrating
Milner's arrangement of Compound Engine

Fig. 51

Fig. 52.

Fig. 53.

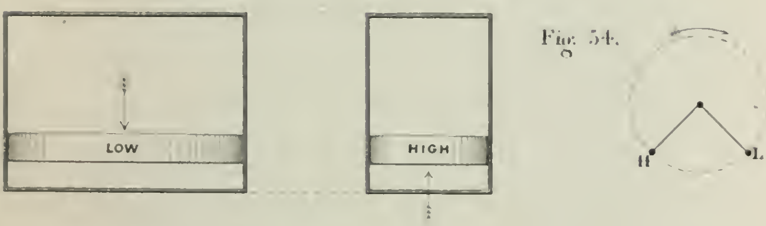


Fig. 54.

Fig. 55.

(Proceedings Inst. M. E. 1872.)

Indicator Diagrams constructed to illustrate action of steam in Milner's arrangement of Compound Engine, Plate 42.

Fig. 56. *High-Pressure Cylinder.*

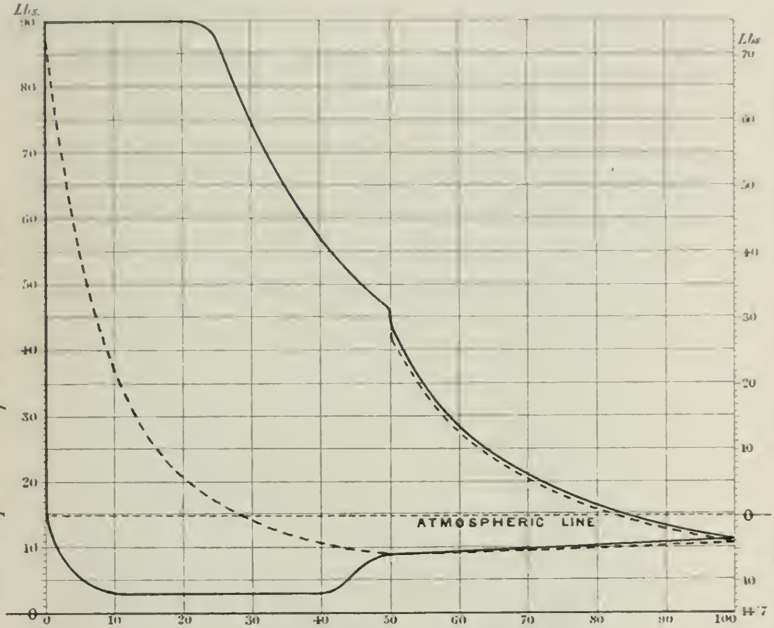
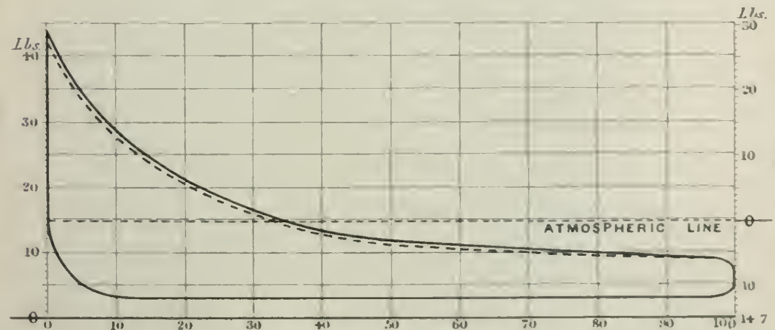


Fig. 57. *Low-Pressure Cylinder.*



Total Pressure, lbs. per square inch.

Pressure above atmosphere, lbs. per square inch.

(Proceedings Inst. M. E. 1872.)

PROCEEDINGS.

30th and 31st July, 1872.

The Annual Meeting of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Tuesday, 30th July, 1872; C. William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

James Bingham Alliott,	Nottingham.
Philimond Bailly,	Brussels.
William Bennett, Jun.,	Liverpool.
Major Frank Bolton,	London.
Henry Brunner,	Warrington.
Arnold Budenberg,	Manchester.
Edward Fidler,	Wigan.
William Heap,	Liverpool.
Alfred Hewlett,	Wigan.
Alexander Carnegie Kirk,	Glasgow.
William Laird,	Birkenhead.
Bradford Leslie,	London.
George Fosbery Lyster,	Liverpool.
Alexander McNeile,	London.
Arthur Shanks,	Calcutta.
Henry Lionel Shirley,	London.
James Nelson Shoolbred,	Liverpool.
William Weldon Symington,	Halstead.
William Teague,	Redruth.

W

Thomas Turton, ...	Liverpool.
Alexander Walker, ...	Oswestry.
William Whieldon, ...	London.
Robert Winstanley, Jun., . .	Manchester.
John Withinshaw, ...	Birmingham.

GRADUATES.

Thomas Armstrong, ...	Sheffield.
Alfred Wilson, ...	Middlesbrough.

The President in opening the proceedings said there were two important subjects that had occupied the consideration of the Council for some time past, to which he had now to draw the attention of the Members.

The first was the question of holding one of the Meetings of the Institution annually in London. The wish having been expressed by several of the Members that a meeting should be held in London once a year, the Council had considered the question carefully, and had come to the conclusion that it was desirable for a trial of such a meeting to be made next year, and the time most suitable for the convenience and advantage of the Members was considered to be in the spring. As however the present rules contained no provision for holding such a meeting, it would be necessary for them to be altered for the purpose; and notice would accordingly be given at the next meeting for enabling the requisite alteration to be made at the Anniversary Meeting in January, that being the only meeting at which an alteration of the rules could be effected.

The second question had regard to the House of the Institution. The present accommodation had now become very insufficient, and the ordinary meetings of the Institution had to be held in a room kindly lent for the purpose. It had long been felt a matter of considerable importance and desirability to have a suitable house for the Institution, as soon as the funds were sufficient to warrant such a step; and the financial position was now very flourishing, the funds of the Institution amounting already to about £8,000, while the annual income exceeded the present expenditure

by more than £700. The Council considered therefore that the time had arrived when, if approved by the Members, steps might be taken for erecting a suitable building. Preliminary enquiries had been made respecting a site in the neighbourhood of the present house of the Institution, and one which appeared eligible having been offered, an approximate plan and estimate had been prepared by the officers for a building sufficient for the present requirements, the amount arrived at being about £12,000. This expenditure would exceed the actual balance in hand by about £1,000, but it was thought that to this limited extent the surplus income might be anticipated. It had been considered desirable to take this early opportunity of giving the Members information regarding this important question; but formal notice was proposed to be given at the next meeting of its being brought forward for discussion at the Anniversary Meeting in January next.

The President further announced that a cordial invitation had been received from the Royal Cornwall Polytechnic Society to hold the Annual Meeting of the Institution next summer in Cornwall; and the Council of the Institution had accepted the invitation, considering it a very desirable one, as Cornwall was a district which had not been visited before, and presented so many objects of interest for the Members of the Institution.

He stated also that a letter had been received from the Royal Commission of the International Exhibition to be held in Vienna next year, inviting the Members of the Institution to aid in promoting a complete representation of British Machinery on that occasion; and he had much pleasure in commending the subject to their attention, and hoped all the Members who were able would assist in furthering this object.

The President continued as follows:—

In consequence of the very courteous invitation which our Institution received last year, we are now assembled in this great town of Liverpool, to discuss with our Lancashire brethren questions

of considerable scientific and practical interest. Considering that only two years have clapsed since Liverpool opened its spacious halls to the British Association, the invitation given to our Institution to hold here our general meeting for the current year speaks well for the scientific interest astir in this community, which is remarkable alike for its commercial and engineering interests.

It behoves me also to congratulate the Institution on the very able and appropriate papers which have been prepared for this occasion, and to call attention to the importance attaching to them, in order that we may be prepared for their discussion. Foremost on the list we find a paper "On the progress effected in Economy of Fuel in Steam Navigation," by a member of our body well known to us all for his power of grasping a subject with a view to bringing out in relief its salient points. This forms an important branch of the general subject of saving fuel, which in the presence of ever increasing demand and of failing supply is rapidly rising into a question of the utmost national importance. The annual coal production in Great Britain amounts at present to 120 millions of tons, which, if taken at 10*s*. per ton of coal delivered, represents a money value of £60,000,000. It would not be difficult to prove that in almost all the uses of fuel, whether for the production of force, for the smelting and reheating of iron, steel, copper and other metals, or for domestic purposes, fully one half of this enormous consumption might be saved by the general adoption of improved appliances, which are within the range of our actual knowledge, without entering the domain of purely theoretical speculation; the latter indeed would lead to the expectation of accomplishing our ends with only one eighth or one tenth part of the actual expenditure, as may readily be seen from the following figures. One lb. of ordinary coal developes in its combustion 12,000 (Fahr.) units of heat, which in their turn represent $12000 \times 772 =$ 9,264,000 ft.-lbs. or units of force, and these represent a consumption of barely $\frac{1}{4}$ lb. of coal per indicated horse power per hour; whereas few engines produce an indicated horse power with less than ten times that expenditure, or say $2\frac{1}{2}$ lbs. of coal. Again the heat required to raise a ton of iron to the welding point of say 2800°

Fahr. requires $2240 \times 2800 \times 0{\cdot}13$ (specific heat) $= 815{,}360$ units of heat, which are producible by $\frac{815{,}360}{12{,}000} = 68$ lbs. of coal; whereas the ordinary heating furnace consumes more than ten times that amount.

Taking account however of a saving of only 50 per cent. in the actual average expenditure, we arrive at an annual money saving of £30,000,000 per annum, a sum equal to nearly one half the national income. Nor does this enormous amount of waste indicate all the advantages that might be realised by strict attention to appliances for saving fuel, which are, generally speaking, also appliances for improving the quality of the work produced; in a national point of view it is of great importance that our coal deposits should be made to last as long as possible; and regarding public health and comfort, the smoke nuisance is the bane of our towns and the chief source of our discomfort in travelling by steamboat or railway, yet smoke emission is only another name for waste of fuel, smoke being nothing more or less than unconsumed coal. I am ready to admit however that the introduction of all coal-saving appliances involves a considerable expenditure, an expenditure which has to be conducted carefully, under the guidance of the mechanical engineer, but which, if properly directed, yields immediate and very ample returns.

In reverting to the important branch of the general subject which will be prominently brought before us, we shall find that our best marine engines consume today rather less than one half the amount of fuel which was thought practically indispensable nine years ago, when our former meeting was held here in Liverpool, showing that one section of our fraternity have at any rate not been idle in the interim. If nine years hence my successor in this chair be able to announce a similar step in advance, which may be looked for I think rather in the mode of producing the steam than in extending its expansive action to a still greater degree, we shall have the satisfaction of knowing that our further discussions of the subject have not resulted in "lost energy."

Another kindred paper on our list deals with the economic getting of coal, and recommends the substitution of a well-considered mechanical process instead of human labour with the pick, which

latter constitutes in my opinion a reproach to our age of professed humanity and mechanical resource, forming as it does part of a system of coal-getting that is susceptible of great improvements, which will tend to cheapen production and to ensure increased safety and comfort to the men.

Another paper deals with interesting applications of hydraulic force to the working of shop tools, being a branch of the same important question of the substitution of machine for hand labour, which commands our special interest at the present time, when the available labour of the country does not nearly suffice for its requirements.

In addition to these we shall have a paper on Buchholz's system of decorticating grain, which is interesting as involving a new process of separating the flour from the grain; of this process we shall have an opportunity of judging by seeing it in actual operation. On a late occasion a plan was brought before us for breaking up the grain by dashing it against the rapidly revolving beaters of Carr's disintegrator; whereas according to Buchholz's plan it is ripped open, and the flour scraped off the bran by a succession of pairs of fluted steel cylinders driven at differential speeds. Without wishing to express an opinion in favour of the one method or the other, it appears to me likely that the rational principles of action involved in each must ultimately triumph, and that the millstone—a contrivance represented on Egyptian monuments and mentioned in the earliest historical records, which has continued to prepare for us our staff of life up to the present day—may be arrested in its meritorious course in obedience to the just but harsh decrees of the most uncompromising of beings, the mechanical engineer of the present day.

It is not my intention to take up the time of the meeting by a lengthy address; enough has been said to illustrate the importance and variety of the subjects brought before us for our information and discussion.

The following paper was then read:—

ON THE PROGRESS EFFECTED IN ECONOMY OF FUEL IN STEAM NAVIGATION, CONSIDERED IN RELATION TO COMPOUND-CYLINDER ENGINES AND HIGH-PRESSURE STEAM.

By Mr. Frederick J. Bramwell, of London.

The writer of this paper has often been struck by the indifference with which for so many years the constructors and the users of Marine Steam Engines regarded the question of Economy in Fuel; and by the fact that, while wonderful progress was made in the increase of the speed of the ships—an increase due greatly to their improved lines, and also greatly due to the much larger real power developed from a given nominal horse power—no one seemed to care about the quantity of fuel burnt, nor to look upon excess in this respect as a stigma on the profession of the mechanical engineer. So much was this the case that the ordinary sources of information used to record with pride that such a vessel had the unprecedented number of 36 furnaces, and that in these 36 furnaces as much as 150 tons of coals could be burnt per 24 hours, and so on. In those days while ships were tried for speed at the measured mile most carefully, to ascertain the last portion of a knot (down to the third place of decimals) that could be got out of them, the question as to the quantity of coals burnt in obtaining this speed was never raised; and the suggestion that there was another trial and a still more important one needed—a trial for consumption of fuel—was never made.

The astonishment one feels on looking back at the long continued apathy as to consumption of fuel in marine propulsion is enhanced when one considers that the mine

owner, the waterworks engineer, the locomotive superintendent, and last, but by no means least, the manufacturer of portable agricultural engines, had been all striving to see to what extent economy could be obtained, although not one of them had the same cause to search after saving as had the proprietors of ocean-going steamships or the builders of marine engines. In all the foregoing cited instances of improvement, the engines, whether fixed or portable, were on land, and the coal could, thanks to the railways and canals of England and to the coasting facilities, be got to them at a comparatively cheap rate; rarely indeed was it that its cost amounted to £1 per ton. But with marine engines for long voyages the case was very different; there every ton of coal carried displaced a ton of cargo on both the outward and homeward voyages, and on the latter journey represented in many instances, where coal of fit quality was not to be obtained at the port of destination, a ton of sailing ship to bring coal from England to that port. Moreover coals don't put themselves upon the fire, although they have done so, and will, it is trusted, do so again; and thus to the cost of the coals, and to the value of the space they occupied, was added the expense of an army of coal trimmers and firemen in each watch, with another army in reserve for the succeeding watch. And yet, in spite of all these incentives to economy, there was for years, as the writer has already remarked, a total disregard of the saving of fuel.

The writer believes this indifference to have arisen from and to have been maintained by a variety of causes. Steam navigation in the outset was confined to coasting voyages, or to passages across the Channel; the duration of the trip rarely exceeded two days, and was much more commonly limited to a few hours. Under these circumstances the quantity of coal to be stored in the bunkers would have been comparatively small, even with the great consumption per hour and per voyage of late years; but in those early days, passengers, and therefore owners, were content with a very low rate of speed. This question of speed, as all engineers know, has a most important bearing on the

quantity of coals consumed; not merely on the quantity per hour, for that a lower rate of speed should reduce the quantity per hour is obvious, and would occur even to one who was not an engineer; but on the total quantity consumed in the voyage, and this is a matter not likely to occur to one not an engineer. It is believed that steam navigation stands alone in this total consumption question. An engineer who pumps water from a mine, or who drives a mill, may do either operation slowly or quickly; if slowly, he will burn per hour fuel reduced in the proportion of the slowness, but the total amount of fuel to do a given job would be practically the same, whether two hours are consumed in pumping out a given quantity of water, or whether he does it in one hour; and so in the instance of the corn mill, and in almost every other case in which power is used. It is true that the railway locomotive, so far as it has the resistance of the air, suffers an increase in the total consumption for the whole journey, if that journey be performed at a greater speed; but this increase applies only to a fraction of the whole quantity of fuel burnt. In marine propulsion however, we know that practically, if a shipowner is content to occupy twenty days for a voyage instead of completing it in ten days, he would in the former case burn only one-eighth the coal per day that he would burn in the latter case, the power required being in proportion to the cube of the speed; and the voyage would be made for one-fourth the total quantity of coal, although the time of the voyage would be doubled. Thus it was that with short voyages and low speeds the coal question was not a very pressing one. Again, when the length of the voyage and the increase of speed gradually came on, the improvements in shipbuilding and the change from wood to iron for their hulls helped the steamship owner. Greater carrying results were obtained without much increase in the fuel; and so the pinch of the fuel question was still postponed, and ship owners were content that engineers should continue to devote their energies to labouring after an extra quarter of a knot per hour.

There was still in reserve an aid to the ocean steamer, and that was the general and all but universal introduction of the screw propeller. The writer doubts whether it has ever been conclusively shown that for a mere trial trip the screw propeller gives better results than the feathering paddle-wheel; but, looking at the efficient manner in which the screw-propeller can be used, whether the vessel be heeled over or not (in which power of efficient use when heeled over is involved the question of the assistance to be derived from the canvass), and looking at the comparative indifference of a screw propeller to a considerable variation in the draft of water, there can be no doubt but that the screw propeller is an aid to steam navigation, and that to its introduction the Marine Engine owed a still further delay in the earnest cry for economy in fuel.

It will be gathered from the foregoing statements that, without any appreciable saving of fuel per horse power, there were causes, such as the better form of ships, the use of iron for their hulls, their increase in size, and the introduction of the screw propeller, by which more tonnage was propelled with the same coal; and that thus the owner was, if not satisfied, at all events not greatly dissatisfied; and in this way, so far as the shipowner was concerned, the demand for economy of fuel per horse power was delayed. So far as the marine engineer was concerned, the question of getting this economy was for many years beset with difficulties. The construction of the marine steam engine employed, and the form of boiler used with it, were inconsistent with attempts at economy. The boiler was made, not so much with a view to strength, as with the object of stowage; and thus marine boilers became huge rectangular covered tanks, as illustrated in Figs. 26, 27, and 28, Plate 33, with fireplaces and flues all having flat sides. Mr. George Dodd, a civil engineer, who in the year 1817 had as many as five steamboats under his direction, said * they made steamboat boilers with flat sides and flat ends "because that figure gives the greatest cubical contents in the smallest space"; and

* See evidence before "Select Committee on Steam Boats," 1817.

Mr. Jessop, although he knew the cylindrical shape to be the strongest, took it for granted that cylindrical boilers would not be used in steamboats, because "the most convenient form of the "boiler is that it should be adapted to the shape of the boat, and "I should think that, that being taken for granted, the safety "would depend upon the strength of the metal and not upon "the form." When the writer of this paper was an apprentice, nearly forty years ago, steam was worked at from $3\frac{1}{2}$ to 5 lbs. above atmosphere, and there was as much pressure of water upon the bottom of the boiler when the steam was down, caused by the mere height of the water in the boiler, as was upon the top when the steam was up; and so great was the risk of the steam falling below the pressure of the atmosphere, that one of the most important fittings of a marine boiler was a valve to admit of an indraft of air, and thus to ensure that the boiler should not collapse under atmospheric pressure. Blowing-off was periodical, and used always to take place from the bottom of the boiler; and when, for the first steamer built for the Atlantic voyage, the "Great Western," a continuous blow-off was arranged, it was effected by a set of brine pumps, which pumped the water out of the boiler into the sea, and thus rendered its going out independent of the fluctuations of pressure in the boiler. Such boilers as these were clearly not of the kind that would suggest high-pressure steam and expansion.

As regards the engines, these were almost universally the inverted beam-engine kind; and those who first introduced them treated them very much as though they were "house engines," that is to say, they relied on the "house" (in this case the vessel) in which the engine was placed, to take the working strain. The engines had framings, it is true, but they had no bedplates, and the vertical strains were taken by huge timber kelsons; the framings did in a sense unite the parts, because one end of a frame was bolted to one part, and another to another, but they were wholly unsuited to take the thrust and pull; and the makers of marine engines were much more concerned to settle whether the side frames should be of the Gothic or the Doric order, whether they should resemble a travesty

of a cathedral window or of a Roman temple, than whether the metal was properly disposed so as to make the engines self-contained structures. With such a condition of things, steady uniformity of low pressure and few reversals of the direction of motion were the matters to be sought after. This was for many years the condition of the boiler and engine.

Moreover there was great public prejudice against the use of high-pressure steam; the accounts of explosions of high-pressure steamboats on the Mississippi were frequent, and were much commented on by the English press; in fact they were kept from time to time before the public, to enforce the censure that was directed against the use of high steam. In England the two explosions of the London and Hull steamer, the "Victoria," in the Thames in 1838, raised great alarm. Unhappily another check to the employment of high-pressure steam was received not many years after. One of the earliest attempts to use comparatively high steam and compound-cylinder engines was made on the Thames in a boat called the "Cricket," which used to ply at half-penny fares from the Adelphi to London Bridge. This boat had been running some time, when the boiler burst, and its external shell was driven endways through the cabin, killing those who were seated there, and rending the hull of the vessel in halves lengthways, so that she instantly sunk. The loss of life was great, and there is no doubt but that this sad accident threw the cause of high-pressure steam and expansive engines back for several years. The engines of this boat were a pair of compound oscillators, the high and low-pressure cylinders of each engine were in one casting, had a stroke of equal length, and their piston rods laid hold of the same crank pin, the pin being made long enough to take the two rods. About the same time, but it is believed somewhat before the date of the "Cricket," Mr. Spiller of Battersea made a small river steamer, which ran for many years with one high-pressure and one low-pressure cylinder. As has been already said, the marine boilers of early days were almost all rectangular flat-sided vessels; and unhappily for the

progress of the stronger, the circular form of boiler, it so happened that both the "Cricket" with its comparatively high steam, and the "Victoria" with its little more than low steam, had circular boilers. The designers of the engines of these vessels no doubt knew in a general way the strength of the circular form; but they seem not to have fully studied the subject. The boiler of the "Cricket" was so made that the firebox blew out of the shell, or rather the shell blew away from the firebox, from want of sufficient endway connection; and the boilers of the "Victoria" were of such a character that it was impossible they could continue to work with safety. Their construction was that of long cylindrical shells, each with an internal cylindrical fire-flue, the axis of the fire-flue being the same as that of the boiler, so that there was a uniformity of water space (3 inches only) all round the flue. The suggestion was that this space should be full of water, and in fact that the water level should stand considerably above the level of the top of the shell, and up into a very small steam-chest with which each boiler was surmounted. There was also in the fireplace a small cylindrical longitudinal tube, just below the crown of the fire-flue, containing water, and hanging from the upper part of the flue by circulating pipes. It will be seen from this description that the only surface from which the steam could escape was that of the water in the steam-chest. These points of faulty construction were not however appreciated by the public; a prejudice was established against cylindrical boilers, and they were judged to be far less safe than the old-fashioned rectangular tanks.

In 1817 the engineers who used the highest steam, Woolf, Simms, Vivian, and Lean, all Cornish men, preferred cast to wrought iron for boilers to bear high pressures; and in this view they were supported by Hall of Dartford, Steel of the same town, and by Tilloch, the editor of the Philosophical Magazine.

Another difficulty with which the marine engineers then had to struggle was the dealing with salt water in the boilers. So long ago as 1838, Messrs. Hall of Dartford (whose name has just been mentioned in connection with cast-iron boilers and who will be hereafter referred to in connection with double-cylinder engines)

constructed the machinery of the "Wilberforce," a boat running between Hull and London, and in this vessel the surface condensers of Hall (of Basford near Nottingham) were employed. The results were perfectly satisfactory; but the fact is that Hall was before his age, and notwithstanding the entire success of the surface condensers in the "Wilberforce," and in some other vessels in which they were employed, the subject of external condensation was treated by the public and by marine engineers as a mere theoretical hobby, undeserving the attention of practical men. Both it, and the extremely elegant plan employed by Howard in his "quicksilver" steamboat, the "Vesta," of cooling down in a refrigerator the injection water, and using the same injection water over and over again, were abandoned; and the simple use of salt-water injection and salt-water feed universally prevailed. This involved a continuous blow-out, or a brine-pump pumping out of the boilers; and although many attempts were made to cause the outgoing brine to give up its heat to the incoming feed water, the contrivances for that purpose were rejected as complications, and thus a large source of loss existed in the continuous stream of water, heated up to the boiling point of the steam, running away into the sea. When suggestions were made for the employment of higher pressure steam, it was alleged (although it is doubted whether there was sufficient or any foundation for the allegation) that high-pressure steam could not be used with salt water, because the deposition on the plates, and the priming, would be so excessive that the engines would not work properly and the boilers would be burnt out.

The writer believes that he has now touched upon the principal causes which rendered the steamboat owner apathetic in demanding economy of fuel, and upon those other causes which rendered the marine engineer indisposed to initiate the use of high-pressure steam; in fact it became a sort of established axiom that there was no good in the use of high-pressure steam. A leading firm of engineers, writing to the commission that was appointed in 1839 to report to the government on what could be done to prevent accidents of all kinds in steamboats, say "our experience has satisfied us that

"there is no economy in working a marine engine with high-pressure "steam, and condensing water being always abundant there is no "necessity; the only temptation is to obtain rather more effect from "an engine of the same weight and cost, though at a great sacrifice "in fuel; but competition in speed is often so great as to supersede "every consideration of safety, economy, or prudence." This may be looked upon as an expression of the highest marine engineering opinion in the year 1839. It may be of interest to record here that in the previous year the whole number of registered steamers in England was 678, of which only one was in excess of 1000 tons burden exclusive of the engine room, and that one was the "British Queen," built at Limehouse in that very year; she is registered as 1053 tons. Next to her came the "Great Western" of 679 tons, built in 1837. Of these 678 steamers, 169 belonged to the port of London, 22 to Bristol, 11 to Southampton, 53 to Glasgow, 48 to Dublin, and only 38 to that town where we are now holding our meeting; but 224 are registered at the port of Newcastle. It will be found however, on looking over the list, that the Newcastle boats averaged only 20 to 25 tons, and that out of the whole 224 vessels there was only one that was over 100 tons.

From this condition of things in 1838 progress was made in the perfection of the work, the greater number of feet run of the piston in a minute, and the construction for screw propulsion of really self-contained engines, not dependent upon the ship for their stability; and it should also be said that in the later days of paddle-wheel engines some beautiful specimens of properly framed self-contained side-lever engines were made, the frames being in some instances entirely of wrought iron. The boiler pressure gradually grew from the $3\frac{1}{2}$ or 5 lbs. of the year 1835, up to the 20 or 25 lbs. pressure with which marine engineers have for some time past been familiar. The boilers also, although they retained the rectangular form of the flat-flued boilers as regarded their shells, were as regarded their interiors brought to the well-known multitubular type, of which an example is shown in Figs. 29 and 30, Plate 33; and these boilers when efficiently stayed were capable of carrying with perfect safety all the pressure which

came upon them. But with the tubular boiler the salt deposit became more serious; the water spaces were less, they were less accessible, and if salt once seriously formed in these boilers, coal was wasted and the boiler was damaged, while the speed of the vessel was impaired for want of a sufficient supply of steam. This led engineers to reconsider the subject of surface condensation, and Samuel Hall's condenser of the "Wilberforce" was revived, was put to work, and was found to be one of the very greatest boons that marine engineers had ever had offered to them. It is true that in some cases difficulties were experienced in a variety of ways, but principally from the wear of the boilers, caused by too great purity of the water leaving the plates unguarded by any crust, and exposed therefore to corrosion; but these difficulties have all been overcome, the chief one, that of the great purity of the water, having been met by the simple expedient of allowing a certain portion of sea water to be introduced into the boiler, just enough to keep a preservative deposit upon the plates and tubes.

Some of the earliest instances of the revival of surface condensation were to be found in the case of the boats plying between Bristol and the Welsh ports. These boats began to use from twenty to twenty-five years back a sort of half high-pressure engine, that is to say, an engine working at from 30 to 40 lbs. above atmosphere and without a vacuum; but the water of the Avon, the Bristol Channel, and the Welsh rivers, changing from fresh to salt and from salt to fresh, and laden with mud in parts, was found so objectionable for the working of such boilers that the engineers were compelled in self-defence to refrain from using it. The first way in which they endeavoured to meet the difficulty was to put fresh-water tanks in the boats, and to carry in these tanks enough to take them their 2 to $2\frac{1}{2}$ hours' trip; but they soon abandoned this in favour of a surface condenser, which was employed not to produce a vacuum, but was made of just sufficient size to turn into water the waste steam from the engines, so as to admit of its being pumped back into the boiler. The circulation through these condensers was effected by the passage of the boat through the water, a proper inlet and outlet being provided in the skin of the ship ahead and astern of the condenser

case, to which the openings were connected by suitable trunks. Such a mode of producing a current was sufficient in condensers of this class; but in the real surface condenser, the "Hall" surface condenser, used to obtain a vacuum and not merely to provide fresh water, the circulation is kept up by means of pumps; these are occasionally reciprocating, but more commonly centrifugal, and very commonly also are worked by a special donkey engine.

The time now came when the necessity of seeking new outlets for industry demanded boats that could economically perform longer voyages than the ten or fourteen days from England to America or to the West Indies, and demanded also the power of putting boats upon foreign stations where no proper fuel could be obtained, except that which was brought at a large cost of freight from the steam pits of South Wales. There now arose therefore a serious demand on the part of the steamboat owner for a more economical style of engine; and foremost among those who led the way to satisfy this demand must be mentioned the names of Messrs. Randolph and Elder, who so long ago as the year 1856 constructed for the Pacific Steam Navigation Co. two paddle-wheel steamers, the "Valparaiso" and the "Inca," using comparatively high-pressure steam, that is to say 30 lbs. above atmosphere, and using it in compound-cylinder engines, which were on the arrangement shown in Plate 22.

Compound-Cylinder Engines date as an invention from the time of Hornblower's engine, shown in Fig. 1, Plate 21, and were revived with the use of high-pressure steam, and were brought into notice by Woolf, with whose name they are commonly associated. Except in the rarest instances, and it is believed these instances were confined to river steamers, compound-cylinder engines were not, prior to their use by Messrs. Randolph and Elder, employed in marine propulsion; but for land purposes they had been by no means infrequently used, although it must be admitted that the single cylinder was much more commonly to be found. Hall of Dartford, whose name has already been mentioned in connection with the "Wilberforce," manufactured compound

engines largely; and they were used almost exclusively by every corn miller within fifty miles of London who added a steam engine to his water power. These compound-cylinder engines were, as regarded their cylinders, of the construction shown in Fig. 1, where the two cylinders are placed side by side and on the middle line of the engine, the high-pressure cylinder being nearer to the centre of the beam than the low-pressure, and thus having a shorter stroke, so that the diminished capacity of the high-pressure cylinder is obtained partly by the shorter stroke and partly by the smaller diameter. Wentworth, another London engineer, who had been brought up at Hall's, also manufactured these engines extensively; Messrs. Hick of Bolton were large makers of them; Edward Humphrys, who afterwards became so well known as a marine engineer, was a most successful manufacturer of the Woolf engine; Messrs. Easton and Amos and many other makers might also be cited.

The progress of compound-cylinder engines was greatly advanced by the use of MacNaught's arrangement, shown in Fig. 2, Plate 21. The high-pressure cylinder was placed on the crank side of the beam; and by this plan many old and uneconomic condensing engines were successfully converted into compound-cylinder engines. There was a certain loss in the length of the passage between the two cylinders; but as a means for improving an existing engine without straining it, this was an extremely good one, because, as the high-pressure cylinder was applied between the beam centre and the crank, the strain on the piston was not passed through the main beam gudgeon, nor had it to be taken by the beam gudgeon bolts, which, as a rule, were in beam engines made far too weak.

The original arrangement of compound-cylinder engines with two cylinders side by side was excellently carried out in the pumping engines by Messrs. Simpson, shown in Fig. 3, Plate 21, upon which a paper was contributed to a former meeting of the Institution ten years ago by Dr. Pole and Mr. Thomson (see Proceedings Inst. M. E. 1862 pages 242 and 259). In these engines a special form of valve was introduced, to economise the passage between the cylinders, and to reduce as much as possible the loss from useless expansion during

the passage of the exhaust steam from the bottom of the high-pressure cylinder to the top of the low-pressure cylinder, or the reverse. Very successful results were obtained with an initial steam pressure of 35 lbs. above atmosphere, and the high economy of 1·67 lbs. of coal per indicated horse power per hour was stated to have been reached.

Having said thus much upon the question of the Woolf engine generally as applied to land purposes, the application of that kind of engine to marine purposes by Messrs. Randolph Elder and Co. will now be reverted to. The question of the quantity of coal consumed was one of vital importance to the Pacific Steam Navigation Co., for whom, as previously mentioned, the first two ships fitted with compound-cylinder engines, the "Valparaiso" and the "Inca," were constructed. Indeed the commercial success of the company became seriously imperilled by the magnitude of the item of fuel in their expenses, owing to the great cost of sending coals to the coaling stations on the Pacific coast. The remarkably successful results obtained by Messrs. Randolph Elder and Co. at the trial of the original compound engines caused the Pacific Co. to extend the plan to their other vessels, which were sent home in succession to have the engines and boilers taken out and replaced by compound engines and high-pressure boilers; and the whole of their fleet, amounting to fifty vessels, have now this type of machinery.

Shortly after this successful application of the compound-cylinder engines to the Pacific Co.'s vessels, other companies turned their attention to this subject, and had some ships in their fleets fitted with engines on the compound principle. It is believed that the application of the compound-cylinder principle to the Pacific Steam Navigation Co.'s boats never suffered any check nor occasioned any disappointment; but unhappily some of the earlier compound engines fitted (but not by Messrs. Randolph and Elder) to the vessels of other companies did not give or did not continue to give the anticipated good results, and were consequently abandoned. It is understood that one great cause for this arose from the imperfect arrangements made for effecting a stuffing-box joint round the piston rod between

the high and the low-pressure cylinder, the high-pressure cylinder in the case under consideration being on the same centre line as the low-pressure, and the pistons being coupled to a common rod. The writer knows that in some instances so serious was the difficulty of maintaining a proper stuffing-box joint at this part, that the box was abandoned altogether, and was replaced by a mere bush made with sufficient clearance to prevent any possibility of the piston rod setting fast, as had happened in the stuffing-box arrangement. It need hardly be remarked that a clearance of this character between the high-pressure cylinder on its pressure side and the low-pressure cylinder on its vacuum side (for this is the condition of things during half the stroke) must have admitted of the passage of an enormous amount of steam direct into the condenser, without producing any useful result. Certain it is that, in the case of some of the vessels which had been fitted for a steamboat company with compound-cylinder engines, it was found necessary to have those engines removed and replaced by single-cylinder steam engines of the ordinary type. This however was only one of those checks that most improvements receive in the course of their development; but it was a very serious check, and for a time retarded the progress of compound engines. That check may now however be looked upon as having been quite got over, for it is the fact that the principle of compound-cylinder engines is now almost universally adopted for ocean steamers on long voyages; and so great are the advantages found to be, that most of the large Steamship Companies are converting their vessels by replacing the original single-cylinder engines with compound ones.

In making this change, much valuable and modern machinery is being cast aside, so that engines which were built only a few years since, which engines are still in excellent working condition, are being broken up and are being replaced by new compound engines and high-pressure boilers. The outlay involved in this sacrifice of good machinery, that might have worked well for years, is of course very large; but the great Steamship Companies, guided only by broad commercial considerations, find it greatly to their

advantage to make this change. In many instances, when the conversion of the engines has taken place, the opportunity of the vessel being laid up has been seized to increase largely its carrying capacity by lengthening the vessel considerably in midships, from 50 to 100 feet according to its original size; the vessel has thus been enabled to carry a much larger cargo, the increase amounting sometimes to more than 1000 tons. This alteration has resulted generally in the larger cargo being carried at the same speed as before, and with a saving of more than one third in the total consumption of coal. In some cases the engines have not been broken up, but all has been retained except the cylinders, and these have been removed and replaced by pairs of high and low-pressure cylinders placed end to end and supported on the old framing; very excellent results have been obtained from these converted engines, the voyages having been made in these instances also with a saving of one third of the fuel previously consumed.

Although the practical carrying out of high-pressure steam and considerable expansion on board ship is being done, as has already been stated, almost universally by the adoption of the compound-cylinder form of engine, the writer considers it to be still an open question whether the same end may not equally well be attained by single cylinders working expansively, either arranged so that the expansion cannot be tampered with, or else put into the hands of truly intelligent men who will not do as their predecessors used to do, namely invariably throw the expansion out of gear. It is to be regretted that fashions prevail in that which ought to be guided entirely by science, namely the construction of Marine Engines. At one time side-lever engines, at another oscillating engines, at another steeple engines, at another trunk engines, and at another double-piston-rod horizontal engines have prevailed. This following of a fashion no doubt arises in a great measure from the engineer being compelled to gratify the wishes of his customer, rather than the dictates of his own judgment. As an illustration of this—in the cases already quoted of the compound-cylinder land engines made by Hall and by Wentworth, their customers were principally corn

millers: one corn miller knew that another corn miller had ground his corn cheaply with a compound-cylinder engine, and it would have been an up-hill task to persuade the miller that he might grind his corn as cheaply with a single-cylinder engine properly constructed. That which had gone before he knew to be a fact, the proposal made to him he treated as a speculation, and he therefore followed his neighbour's lead and ordered a compound-cylinder engine. In the same way, at the present date, a shipowner knows that a certain ship is reported to have made a certain voyage in a certain time with only two-thirds of the ordinary consumption of fuel; he enquires how it was done, and finds it was done by a compound-cylinder engine, and thereupon, and not unnaturally, he thinks that he also will have a compound-cylinder engine. Theoretically there can be no doubt but that steam may be as advantageously expanded in one cylinder as in two; and even more advantageously, on account of a certain inevitable loss in the passages between the two cylinders of the compound engine, which loss does not arise when the expansion is made all in one cylinder. Further a single cylinder has the advantage of a single piston friction and of a single piston leakage. Moreover the high-pressure cylinder (except slightly in one instance to be hereafter mentioned) adds nothing whatever to the work done; just as much, in fact somewhat more, effect would be got out of the same weight of steam, were it introduced into the low-pressure cylinder at once: and thus the reflection is forced on one, that in using steam in compound-cylinder engines, the whole of the high-pressure engine is absolutely useless as a source of power, and in that respect therefore is all waste of weight, of space, and of money.

But it is said that where the expansion is continued in one cylinder, the pressure is so various throughout the stroke that undue strains are caused at particular times, and the power to give rotary motion is by no means uniform. With respect to this latter question, for marine work a pair of engines is in England almost universally employed. These engines are placed at right angles, they make for screw propellers from 45 to 100 revolutions per minute, and even at the lower of these speeds the

same condition of pressures must recur at every quarter revolution or 180 times per minute or 3 times per second. Screw engines working as slowly as this are of large size, and have large propellers, probably 20 feet diameter and weighing about 14 tons. These propellers certainly act as flywheels, and it is a question well worth investigation, what, with a high expansion, say cutting off at 1-10th of the stroke, would be the variation in velocity of a propeller as the pressures varied in each quarter of a revolution. The writer believes it would be found to be something extremely small, so small indeed as to be wholly unworthy of attention, in a case where variation of resistance has to be encountered at every instant, due to the difference of immersion of the vessel and of the screw caused by the pitching or scending of the ship, and due to the blades passing the stern opening. He doubts whether the most strenuous advocate of the compound-cylinder engines could show that there was any necessity, on the score of equable rotary motion, to apply them to steamboats, in preference to a pair of single cylinders working with high expansion and acting on cranks placed at right angles. Uniformity of tangential force, to produce uniform rotary motion, is no doubt essential in a spinning mill, where the speed of revolution of the engine may be multiplied 300 to 400 times before it reaches the spindles ; but the same considerations cannot apply to marine propulsion. If they did, how would it be possible to work a steamboat successfully with a single engine, whether for screw or paddle? but it is known as a fact that the best river boats of the Americans have only single engines, and that even on the Mississippi and other Western waters where two engines are employed, these are wholly unconnected, and each works its own paddle-wheel independently of the other. Moreover some of the most remarkable passages have been made with single engines in screw vessels. Even assuming it to be the fact (which it is not) that in these single-cylinder engines there had been but little expansion, and that the load on the piston had therefore been nearly uniform throughout the stroke, nevertheless the tangential force to produce rotary motion must have varied from nothing when the crank was on either of its centres, to full

force when the crank was at half stroke—a variation far greater than would obtain with a pair of single-cylinder engines having high expansion in each cylinder; and yet, as already stated, these single engines work well.

Variations in tangential force throughout a revolution are illustrated in Plate 35. In the case of the effective steam pressure being uniform throughout the whole stroke, as in the indicator diagram, Fig. 33, and with a single cylinder, the variation in tangential force (neglecting the effect of obliquity of the connecting rod) is shown by the shaded portion in Fig. 34, the mean force being indicated by the dotted circle A A. The shaded portion in Fig. 35 shows the variation with two cylinders of half the area working cranks at right angles, the deviations from the mean dotted circle A A being then for very short periods and even for these periods very small, amounting to only about 20 per cent. In Figs. 37 and 38 is a corresponding illustration of the variation in tangential force, in the case of a uniform steam pressure through half the stroke and expansion through the other half, as in the indicator diagram, Fig. 36; and although with a single cylinder, as in Fig. 37, the variation is greater than in Fig. 34, with two cylinders at right angles, as in Fig. 38, the extreme deviations from the mean force are rather smaller than in Fig. 35, amounting to only about 14 per cent. A similar illustration is given in Fig. 40 from the actual indicator diagrams of a compound marine engine working cranks at right angles (the "Spain," Fig. 41), the high-pressure diagram in Fig. 39 being reduced to one third in vertical scale, so as to allow for the cylinder being only one third the area of the low-pressure cylinder; the extreme deviation from the mean tangential force, as shown in Fig. 40, amounts to about 26 per cent. Further it must be borne in mind that, as will be presently alluded to, the forces to produce rotation are not exactly in accordance with the pressures of the steam, because those pressures are modified by the inertia and by the momentum of the parts; and thus the diagrams in Plate 35, which are based on the steam pressures alone, give discrepancies in tangential force greater than those which occur in actual practice.

The second and the more common objection to expansion in single-cylinder engines is, as has been already alluded to, the alleged great irregularity of the strains on the working parts. It is urged that in a single-cylinder engine cutting off at a high expansion, say at 1-10th of the stroke, there is a great shock upon the parts in consequence of the full pressure of the steam acting upon the whole area of the piston of the single cylinder; but the writer thinks it can be shown that this shock, or rather strain, is by no means so serious as is often supposed, and that moreover at the very time when the greatest strain is given by the steam there is a resistance from the inertia of the parts in the opposite direction, which tends to balance to a certain extent that of the steam; and in very quick running engines, say in those working 120 revolutions per minute, this momentum question goes a very long way towards neutralising the strain of the strong steam. Let the case of a compound-cylinder engine having one cylinder of 60 inches diameter and the other of 106 inches, the strokes of these cylinders being equal, be first investigated. Assume that 70 lbs. boiler steam be put into the 60 inch cylinder at the commencement of the stroke, while below the piston there may be steam of about 10 lbs. above atmosphere; the piston rod of that cylinder will be exposed to a pressure of only about 75 tons; while upon the low-pressure piston there would be at the commencement of the stroke a pressure of probably 10 lbs. above atmosphere and a vacuum of 12 lbs. below it, making a total of 22 lbs. per inch, which upon the area of the 106 inch cylinder would give about 85 tons upon the piston rod of this cylinder, making an aggregate strain of 160 tons from the two cylinders. It may be urged that if a single cylinder of 106 inches diameter had been employed, the initial pressure upon such a piston would have been 70 lbs. above atmosphere and 12 lbs. below it, making 82 lbs. total per square inch, or about 320 tons strain on the piston rod, being double the aggregate of 160 tons obtained by adding together the pressure upon the high and low-pressure piston rods in the case of the compound engine. But it must be remembered that to obtain the same power as would be obtained from such a compound engine, two single cylinders of only about 75 inches diameter would

be required, instead of the 60 inch and 106 inch cylinders of the compound engine; and the strain upon the two piston rods of the single cylinders with the same initial pressure and vacuum would not even then exceed about 160 tons upon each, as compared with the 85 tons upon the rod of the low-pressure cylinder in the compound engine arrangement. But the fact is that to obtain the same power by expansion in the pair of single cylinders as is obtained in practice in the compound-cylinder engine, the initial pressure would not require to be so high as it must be in the compound engine: for it is shown by the combined indicator diagram in Fig. 42, Plate 37, afterwards described (which is taken from a compound engine with cylinders of 60 and 106 inches diameter), that there is a loss of as much as 10 per cent. from the full effect of the expansion curve that would be obtained from the same steam in a single cylinder with the same initial pressure, as shown in Fig. 43. In a single-cylinder engine therefore, where this loss would not occur, an equal amount of work could be got with a somewhat lower initial pressure of steam, by calculation about 63 lbs. above atmosphere. This leaves however on each piston rod of the single-cylinder engine about 150 tons; and there would accordingly be, during the first tenth of the stroke, a strain upon the piston rods of the single-cylinder engine about 76 per cent. in excess of that upon the rod of the low-pressure cylinder in the compound arrangement. But this greater strain in the single-cylinder engine could be met by an appropriate addition to the bearing surfaces and to the strength of the parts. So far as the cylinder castings are concerned, it appears that the machinery would be less cumbrous and the framing smaller, to arrange a pair of 75 inch cylinders than the compound cylinders of 60 inches and 106 inches diameter. Moreover a pair of single-cylinder engines may have, as is so commonly practised, a slide-chest common to the two, as in locomotives; and they possess many other advantages of simplicity.

The writer has thought it well to consider what can be said in favour of expansion in single-cylinder engines. He knows very well that one of the companies trading from the Thames—

the St. Petersburg Steamship Co.—when under the charge of Mr. William Horn, worked with single cylinders in the most satisfactory manner, obtaining a gross indicated horse power for just about 2 lbs. of coal. But looking at the tendency towards higher pressure and greater expansion, the writer thinks that in all probability the advocates of the compound engine are right, and that these engines come in as a most valuable and efficient aid in carrying out the principle of high pressure and high expansion, as by their means the area exposed to high pressure is limited to a moderate sized piston, and only a medium cut-off at $\frac{1}{2}$ or $\frac{1}{4}$ stroke is required, such a cut-off as can be well done by an ordinary slide-valve with separate cut-off slide: whilst the second cylinder enables the expansion to be carried to a very high degree without involving any practical objections.

In Fig. 41, Plate 36, is shown an example of an indicator diagram from one of the largest class of ocean steamers, the "Spain," running between England and New York, having a compound engine with two cylinders of 60 and 106 inches diameter and $4\frac{1}{2}$ feet stroke, working to cranks at right angles, and having an intermediate vessel between the high and the low-pressure cylinder. This indicator diagram was taken on the trial trip, when making 52 revolutions per minute or 468 feet per minute speed of piston, and developing 3043 indicated horse power. The boiler pressure is 75 lbs. above atmosphere, and the initial pressure in the cylinder 72 lbs.; the steam is cut off at about half stroke at a pressure of 55 lbs., and then expanded down in the small cylinder, from which it is exhausted into the intermediate vessel, and from there into the large cylinder at 10 lbs. pressure, and then further expanded down to 10 lbs. below atmosphere, and discharged into the condenser.

Another example of indicator diagram from another marine engine of the same class, having one high and one low-pressure cylinder working cranks at right angles, is given in Fig. 44, Plate 38, ("City of Bristol," No. 13 in the appended Tables of marine engines); and in Fig. 46, Plate 39, is given the indicator diagram from a similar engine, but with cranks at an angle of 135° instead of at right angles. In Fig. 47, Plate 40, is shown the indicator

diagram from another of the same class of compound engines, which was put into a vessel in place of the original pair of independent cylinder engines; and the indicator diagram from the original single engines is shown in Fig. 48, ("Persian," No. 1 in Tables). The original engines had two 54 inch cylinders, and the compound engine had 42 and 75 inch cylinders; they were both vertical direct-acting engines working cranks at right angles, and both having surface condensers; but the original boilers were worked at 20 lbs. pressure, and were replaced by boilers working at 60 lbs. pressure. The vessel was not altered, and continued working under the same conditions, but at a somewhat greater rate of speed; and the consumption of coal, which averaged previously 38 tons per 24 hours, and 4·34 lbs. per indicated horse power per hour, is stated to have been reduced by the alteration of the engines to $24\frac{1}{2}$ tons per 24 hours, and 2·80 lbs. per indicated horse power per hour.

It should have been previously stated that there are two main classes of compound engine: the first, that in which the pair of cylinders work together, or directly opposite to each other; and the second and more usual, that in which they work cranks at right angles.

The former, which is the original Hornblower or Woolf arrangement, is the nearer to perfection in the distribution of the steam, as the cylinders work into each other correctly, the commencement of the steam stroke in the low-pressure cylinder corresponding to the commencement of the exhaust stroke in the high-pressure cylinder. But unless the single pair of cylinders be trusted to, as has been done with great success, the circumstance that the two pistons are on the centre at the same time involves a second pair of cylinders working at right angles to the first: either two pairs side by side, as in Figs. 7 and 8, Plate 23; or each pair combined for the sake of compactness, with the high-pressure cylinder on the top of the low-pressure, as in Fig. 9, Plate 24, ("Neera," No. 28 in Tables); or with the low-pressure cylinder at the top, as in Fig. 10, Plate 25. In another arrangement, shown

in Figs. 11 and 12, Plate 26, ("José," No. 6 in Tables), the two cylinders are combined by placing one within the other, the low-pressure cylinder having an annular piston working outside the high-pressure cylinder, with two piston-rods which are fixed to the same crosshead as the centre piston-rod. This arrangement it is thought was originally proposed as long back as 1837 by William Gilman, and it has for many years been used by a London engineering firm in the construction of engines to drive corn mills; but the writer believes that care has never been taken to steam-jacket the high-pressure cylinder, which has thus always been bathed in the atmosphere of the low-pressure; this the writer looks upon as the cause of considerable loss. In Fig. 45, Plate 38, is shown the indicator diagram from the annular compound engines in Plate 26, which were put into a vessel in place of the original pair of independent cylinder engines. The original engines had two 46 inch cylinders, and the compound engines had two pairs of cylinders of 22 and 52 inches diameter, the 52 inch cylinders being annular and equivalent in area to $44\frac{1}{2}$ inches diameter; both were vertical direct-acting engines working cranks at right angles, but the original engines had injection condensers and the compound ones surface condensers, and the boiler pressure of the original was 15 lbs. and of the compound engines 48 lbs. The vessel was lengthened 30 feet at the time of the engines being altered, adding 400 tons to the cargo space, and continued working at the same speed as before; but the consumption of coal, which averaged previously 24 tons per 24 hours, and 4·60 lbs. per indicated horse power per hour, is stated to have been reduced by the alteration of the engines to 11·2 tons per 24 hours, and 2·12 lbs. per indicated horse power per hour.

In the other class of compound-cylinder engines the two cylinders work cranks at right angles, as shown in Figs. 13, 14, and 15, Plates 27 to 29, ("City of Bristol," No. 13 in Tables), and the low-pressure cylinder does not open to take the steam until the middle of the exhaust stroke of the high-pressure cylinder; an intermediate reservoir is consequently employed, into which the exhaust steam expands from the high-pressure cylinder during the

first half of the exhaust stroke. The pressure in this reservoir increases towards the middle of the stroke, as the high-pressure piston travels back and reduces the total capacity; but as the content of the reservoir is large, about three times the capacity of the high-pressure cylinder in the example shown, the actual rise of pressure is only about 3 or 4 lbs. The connection between the reservoir and the low-pressure cylinder is cut off at about half stroke. In Fig. 16, Plate 30, is shown a vertical section of the cylinders and valves to a larger scale.

The action of the steam in this engine—which is the form of compound-cylinder engine now most generally adopted for marine purposes—is illustrated in the diagrams, Figs. 17 to 23, Plate 31. The beginning of the stroke of the high-pressure cylinder is shown in Fig. 18, with 72 lbs. steam above the piston, and 10 lbs. steam below it, being the pressure in the reservoir into which the cylinder is exhausting. At half stroke, in Fig. 19, the steam is cut off at 55 lbs., as shown in the sketch of the indicator diagram given in Fig. 23. The low-pressure cylinder then opens for the upstroke, taking steam below the piston from the reservoir, with the condenser vacuum above the piston; the pressure of steam in the reservoir is at that time raised a little above the 10 lbs. by the return of the high-pressure piston, but this increase of pressure is lost in the passage before the steam enters the low-pressure cylinder. In Fig. 20 the low-pressure cylinder is at half stroke and cut off from the reservoir, and the high-pressure cylinder is at the end of its stroke; and at the end of the upstroke of the low-pressure cylinder, in Fig. 21, the steam below the piston is expanded down to 10 lbs. below atmosphere on escaping into the condenser.

This arrangement of a compound engine with two cylinders, one high and one low-pressure, working cranks at right angles, has the important practical advantage of not causing increased complexity and of not demanding increased space, as compared with a pair of ordinary single engines, the whole being identical in these respects, excepting the increased size of cylinder; but as one engine is entirely dependent upon the other in its action, some anxiety has been felt as to the results in the case of either engine happening to break down

at sea. This question has just been practically answered in a most satisfactory manner, by the results of an accident that disabled the low-pressure cylinder of the large vessel, the "Spain," with 60 and 106 inch cylinders, which has been referred to before, and the indicator diagram from which is shown in Fig. 41, Plate 36. The accident happened on the second day of the run home across the Atlantic, by the breakage of the low-pressure piston. The engine was again got to work by disconnecting the disabled portion, and taking out the slide-valve of the low-pressure cylinder, so that there was a clear passage from the high-pressure cylinder to the condenser through the low-pressure cylinder. The high-pressure cylinder was then worked as an ordinary condensing engine, the precaution being taken of lowering the boiler pressure from 75 to 40 lbs. to avoid any risk of overstrain; and the vessel was brought safely home with the single engine within a couple of days of the regular time. An indicator diagram from the engine during this run is shown by the dotted lines D D in Fig. 41, Plate 36, the speed being 35 revolutions per minute and the power developed from the single cylinder 982 indicated horse power.

In Figs. 4 to 6, Plate 22, ("Arequipa," No. 19 in Tables), is shown the form of the original compound-cylinder engine of Messrs. Randolph and Elder, which has been employed also by several other makers. It has two cranks, one opposite the other, the two high-pressure cylinders working on one crank and the two low-pressure on the other; thus the high-pressure piston of either compound engine is at one end of its stroke when the low-pressure piston of that engine is at the opposite end of its stroke. The two compound engines are inclined to each other, to answer the purpose of the ordinary right-angled cranks for passing the centres; the angle of inclination is usually 60°, but sometimes higher, up to 90°, when the space available for the engines is sufficient.

In Figs. 24 and 25, Plate 32, is shown an arrangement that has been used in the French navy, consisting of three horizontal cylinders working to cranks at equal angles of 120° each, the centre cylinder being the high-pressure one, and exhausting into the two

side ones. All the cylinders are the same size, about 70 inches diameter and $4\frac{1}{2}$ feet stroke in the instance shown, and the relative capacity of the high and low-pressure cylinders is therefore 1 to 2. The object of this arrangement is to obtain greater uniformity of driving power by having a three-throw crank.

By arranging compound engines with two pairs of cylinders, and those in each pair working cranks that are opposite to each other, either as shown in Plate 22 or as in Plate 23, some advantage is obtained in partially balancing the strain upon the crank shaft when the power of the high and low-pressure cylinders is nearly equal, as they press in opposite directions simultaneously upon the crank shaft, and thus there is a decreased friction upon the bearings, from their not having to bear a large portion of the strain of the engine, as is the case with right-angled cranks. This point was specially brought out by Mr. John Elder, by whom the friction of the crank shaft was thus reduced considerably in some of his arrangements of compound engines.

In the ordinary arrangement of compound engines—in which the high and low-pressure pistons work at right angles, with a reservoir between them—the effect obtained is illustrated in the combined indicator diagram, Fig. 42, Plate 37, taken from the "Spain" indicator diagram in Fig. 41, previously referred to; but in Fig. 42 the high-pressure diagram is drawn to about one-third the horizontal scale, to make the areas of the high and low-pressure diagrams in accordance with the power of the two cylinders, the areas of which are in the proportion of 1 to 3·12. The two diagrams when thus combined can be correctly compared with the corresponding continuous expansion diagram in Fig. 43, that would be obtained from the same steam if it could be expanded to the same extent in a single cylinder, the expansion curve being drawn through the point of cut-off in the high-pressure cylinder. The difference between the shaded areas in Figs. 42 and 43 shows the loss resulting from the pistons working at right angles and exhausting into the intermediate reservoir, and amounts to about 10 per cent. of the effect that would be obtained if the whole expansion were performed in a single cylinder.

In Figs. 51 to 55, Plate 42, is shown another mode of dealing with compound cylinders when placed at right angles. In this case no intermediate vessel is used, but when the engine is running ahead the top of the high-pressure cylinder exhausts directly into the top of the low, and the bottom of the high into the bottom of the low: while it would be only during the short time that stern-way was required that the steam from one end of the high-pressure cylinder would be compelled to pass to the opposite end of the low-pressure cylinder. In Fig. 51 the high-pressure cylinder is shown with its crank at half stroke and at 90° ahead of the low-pressure cylinder, the steam in the high-pressure having been cut off at one fourth of the stroke. In this position, the opening to exhaust from the high-pressure and to admit to the top of the low-pressure has just been made, and the steam is supposed to be passing into the low at a pressure half that of the initial pressure. Suppose for example that steam at 75 lbs. above atmosphere or 90 lbs. above zero had been used as initial steam; then the pressure about to come on to the low piston would be one half of that or 45 lbs. above zero. Assume now that the cranks had gone forward 45°, the position would be as shown in Fig. 52, and then the high-pressure piston would have made 85 per cent. of its stroke, and the low-pressure 15 per cent. of its stroke; the collective contents of the two cylinders, the low-pressure cylinder being double in area of the high, would be 115 per cent. of the high-pressure cylinder; and the steam that was cut off at 25 per cent. of the high would now be expanded $4\frac{3}{5}$ times, equal to $19\frac{1}{2}$ lbs. above zero. Fig. 53 gives the condition at a further 45° of the revolution. By this time the high-pressure piston has completed its stroke, and the low has reached half stroke, giving 100 per cent. of the high and 50 per cent. of the low, equal in all to 200 per cent. of the high, and 8 times expansion or $11\frac{1}{4}$ lbs. above zero. Fig. 54 shows the condition of things at the next 45°. Here the high-pressure piston has come back 15 per cent. of its stroke, leaving 85 per cent.; and the low has made a total of 85 per cent. of its stroke, equal to 170 per cent. of the high, or 255 per cent. collectively, which gives $\frac{1}{10 \cdot 2}$ expansion or $8\frac{3}{4}$ lbs. above zero. At the next 45°, shown by Fig. 55, the high-

pressure piston has returned to half way or 50 per cent., and the low is at the end of its stroke or 100 per cent., equal to 250 per cent. of high and low combined, or 10 times expansion and 9 lbs. above zero. At this point the exhaust opens from both the low and the high cylinders to the condenser, and remains connected with the high until the piston of that cylinder has reached the end or nearly the end of its stroke. In Figs. 56 and 57, Plate 43, the full lines show approximately the high and low diagrams resulting from such an arrangement. The plan above described is that of Mr. Milner, which was published in the year 1853. He had an ingenious contrivance, by which, when it was necessary to go astern, the steam could be taken from the top of the high-pressure cylinder to the bottom of the low, and from the bottom of the high to the top of the low-pressure. If the same arrangement be made, but the exhaust from the high-pressure be allowed to go into the slide-jacket of the low-pressure, in the ordinary manner of compound engines on land (a system which involves at all times filling the passages that communicate from one end of the cylinder to the other), then no special arrangement is required for going astern. The result is not quite so good, as the expansive figure is not so near the true curve, and the steam in the high-pressure cylinder has to be compressed; but even after allowing for these drawbacks, the effect is very good, as may be seen by the dotted lines in Figs. 56 and 57, which show approximately the high and low diagrams following from such a disposition of the engines These are constructed on the assumption that the passages of the two cylinders and the slide-jacket of the low-pressure cylinder would amount to 5 per cent. of the whole capacity of the high-pressure cylinder. With either the plan of Milner or with that shown by the dotted lines, it will be seen that the maximum strain on the high and low piston-rods is practically equal. When working as Milner proposes, a small percentage of additional work is got out of the high-pressure cylinder.

The instances quoted and the diagrams given from marine engines have all been from the merchant service; but it would not be right to omit from a paper on compound engines a most

successful application of them to the royal navy. In the year 1870 H. M. S. "Briton" was fitted by Messrs. J. and G. Rennie with a pair of compound engines on the plan of Mr. E. A. Cowper. In these engines the cylinders worked to cranks at right angles; the high-pressure cylinder exhausted into an intermediate vessel, steam-jacketed in a peculiar manner, so that the steam on its passage into the vessel did not come into contact with the jacket, but did so most thoroughly on its way out of the vessel to the low-pressure cylinder. These engines were of 350 nominal horse power, the high-pressure cylinder was 57 inches diameter and the low-pressure $100\frac{1}{4}$ inches, the stroke of each piston was $2\frac{1}{4}$ feet, the mean draft of water of the ship was 15 ft. 2 ins., the average pressure of steam in the boiler when working at full power was 58 lbs. above atmosphere, the vacuum in the condenser was 27 inches, the mean revolutions per minute were $95\frac{1}{4}$, the mean pressure in the high-pressure cylinder was 25·9 lbs., and in the low-pressure 8·7 lbs. At this time the indicated horse power was 2148, and the speed of the vessel 13·12 knots per hour. The engines drove a two-bladed Griffiths screw of $14\frac{3}{4}$ feet diameter and 16 feet pitch. The results obtained were extremely good. When the engines on the six hours consumption of fuel trial were developing a little below their maximum power, namely 2018 indicated horse power, and when the ship must therefore have been making about 13 knots per hour, the consumption was 1·98 lbs. of coal per indicated horse power per hour; but when the speed was reduced to 10 knots, which speed was maintained by 660 indicated horse power, the consumption of coal was as low as 1·30 lbs. per indicated horse power. So far as the writer knows, this is the greatest economy that has ever yet been reached in any kind of steam engine for any purpose. Fig. 49, Plate 41, shows the diagrams that were taken from this engine during the full power trials; while Fig. 50 shows a pair taken from the 10 knot speed run.

The advocates of the compound engine as at present used for marine purposes put forward as an advantage the protecting the high-pressure cylinder from the cooling effect of the condenser,

as they say that the low-pressure cylinder alone is exposed to the condenser. Assuming the high-pressure cylinder to be properly steam-jacketed, it is doubtful whether this cooling effect is of much value, or at all events whether it is of anything like the same value as the extra area of indicator figure obtained in the high-pressure cylinder by the condenser connection. The diagram of Milner's arrangement in Fig. 56, where the high-pressure cylinder is connected with the condenser, shows by the full line the large amount of extra working pressure in that cylinder due to this connection. In the arrangement illustrated by the dotted line, the condenser connection does not take place, and there is on the contrary the cushioning pressure before referred to.

The construction of Marine Boiler for sustaining the higher pressures of steam now in use is a subject of essential importance for efficiently carrying out the advantages of high expansion in compound engines; and the progress of their application was seriously impeded at the first, as has already been noticed, by the unsuitability of the boilers in use at the time for carrying the higher pressures required. The ordinary form of marine boiler previously used is illustrated in Figs. 29 and 30, Plate 33, and contained the large extent of flat surfaces in the flues and shell which has been alluded to, all of which required staying. Such boilers were not commonly adapted for standing more than a moderate pressure of about 20 to 30 lbs.

A common form of the present high-pressure marine boiler used for 60 to 80 lbs. steam is shown in Figs. 31 and 32, Plate 34. It consists of a single cylindrical shell with flat ends, and three cylindrical furnaces at each end, delivering into vertical uptake flues in the centre of the boiler, from which the tubes pass to the front and back; the flat sides of the uptake flues are stayed together, and their roofs are supported by crown girders; the flat ends of the shell are stayed by longitudinal bolts. These boilers are of large size, those shown in Figs. 31 and 32 being $13\frac{1}{4}$ feet diameter and 18 feet long, constructed of $\frac{7}{8}$ inch plates double-riveted. The tubes are of iron, 434 in each boiler, $6\frac{1}{2}$ feet long

and $3\frac{1}{2}$ inches diameter; and the furnace tubes are $3\frac{1}{4}$ feet diameter with 6 feet firegrates. The heating surface is 575 square feet in the furnaces and flame-box, and 2530 square feet in the tubes, making 3105 square feet total in each boiler; the firegrate area is 117 square feet in each. The boilers shown in Figs. 31 and 32 are those belonging to the engines illustrated in Plates 27 to 29, ("City of Bristol," No. 13 in Tables). Two boilers are combined, with one funnel; and two large steam receivers, $4\frac{1}{2}$ feet diameter and 18 feet long, are fixed across the base of the funnel, by which means a slight superheating of the steam is obtained. Some marine boilers have been made as large as 14 or 15 feet diameter, with $1\frac{1}{8}$ inch and even $1\frac{1}{4}$ inch plates for the shell. In Table II are given the particulars of a number of recent examples of these boilers by different makers.

Superheating of the steam was formerly carried to a considerable extent, and many special contrivances were used for the purpose; but these are now practically discontinued for general use, and the simple plan is generally adopted of exposing the steam receiver to the heat of the base of the funnel. This serves to dry the steam thoroughly before passing to the cylinders, without raising its temperature so high as to cause risk of damage to the packing of the piston and piston rod.

A variation which is occasionally made in the high-pressure boiler consists in having a common flame-box in the middle, into which both the forward and aft furnaces draw. In these cases vertical tubes of large size are introduced, which serve the purpose of staying the top and bottom of the flame-box, and of causing a circulation of water, and also of affording extra heating surface. It is said that this practice of introducing both sets of furnaces into a common box assists in the perfect combustion of the fuel, and that there is no difficulty experienced in obtaining a practical equality of draft back through both sets of tubes.

A great deal more might be said upon this subject of high-pressure marine boilers, as regards the questions of safety, of care in the manufacture with plates of such great thickness, of endurance, and of many other points; but such a question would be far too long

to enter upon here, in fact there is quite enough in it to form the subject of a separate paper. The writer will merely remark that he believes high-pressure boilers have an advantage in freedom from priming which is not commonly appreciated, and indeed is sometimes absolutely denied. The freedom from priming arises principally, as he thinks, from this point: that not only is a horse power obtained with a less weight of steam in these high-pressure expansive engines than in the old form of engine with low pressure, but that this weight of steam is delivered from the water at a density say of 5 to 6 atmospheres above zero, while the low-pressure steam was delivered at only 2 to 3 atmospheres above zero; or speaking roundly, the steam in these compound engines comes from the surface of the water in the boiler in half the bulk that the same weight of steam would have occupied in the old-fashioned form of engine. Even therefore if the same weight of steam per horse power were used now as formerly (which of course is not the case, for if it were there would be no economy), that steam would only be half the bulk on leaving the water in the boiler; and thus if the same number of bubbles are given off now as formerly, each bubble will be of half the cubic contents; or if the bubbles be of the same contents, then in any interval of time only half the number will be given off. In this way, so far as regards the disturbance of the water either in its bulk or at its surface, a high-pressure boiler working steam of double the density of another boiler has its water no more disturbed than the low-pressure boiler would have if it were evaporating half the weight of steam. Thus the high-pressure boiler is put into as tranquil a condition, as regards its water, as the low-pressure would be in if the engines were working at only half power.

The other great element in Marine Engineering of the present day is the Surface Condenser. This however, like the Boiler, is a subject for a separate paper; and the writer will therefore content himself with referring to Plates 27 to 29, in which is shown one of the surface condensers now in use, and of the horizontal construction. In this the tubes, which are of brass,

are $\frac{3}{4}$ inch diameter with $\frac{3}{8}$ inch spaces, the sizes generally employed being from $\frac{5}{8}$ to 1 inch diameter. They are fixed in the brass tube-plates at each end, and various modes have been devised for doing this; probably few, if any, are better or simpler than the original stuffing-box plan of Hall. In the instance shown, the tubes are divided into three tiers, by horizontal partitions in the water compartments at the ends; and the current of water from the circulating pump is forced first through the lower tier, then back through the middle tier, and lastly through the top tier of tubes. The exhaust steam from the engine enters the condenser at the top, and quits it at the bottom, so as to come in contact last with the coolest tubes at the bottom. Condenser tubes are employed of various lengths from 6 to 15 feet, and when long are supported by intermediate diaphragms to prevent vibration. In the example shown there are 1725 tubes, 13 feet long, giving a total condensing surface of 4504 square feet. In another arrangement of condenser, as shown in Fig. 8, Plate 23, the tubes are placed vertically, and the circulation of the water is from the bottom to the top, without any separating partitions. The vacuum maintained by the surface condensers is from 25 to 29 inches of mercury. In Table III are given the particulars of a number of recent examples of these surface condensers by different makers.

In Table I is shown the average consumption of coal per indicated horse power per hour by nineteen different vessels, all having compound engines, in voyages made in 1868 to 1872, from England to North and South America, to the East Indies, and in coasting voyages from England to Scotland; the general average is seen to be 2·11 lbs. per indicated horse power per hour. The consumption in the several cases is obtained by taking the total consumption of coal on the voyage, and the average horse power shown by indicator figures taken from the engines at various times during the voyage. In Table IV are given the particulars of the voyages referred to. In the trial trips of a number of similar vessels the consumption was from 1·90 to 1·62 lbs., the average being 1·76 lbs. per indicated horse power per hour.

In conclusion the writer desires to express his special acknowledgements for the valuable information that has been so liberally supplied in reference to this paper by a number of the principal marine engineers; and he trusts that the great importance of the subject to Engineers and Steamship Owners, as well as to the public generally, will induce all who can supplement any unavoidable deficiencies in the present paper to communicate further practical information in the discussion.

TABLE I.

Average CONSUMPTION OF COAL *per Indicated Horse-power per Hour, by Steam Ships with Compound Engines in long sea voyages.*

Engines.		Cylinders.			Revs. per min.	Piston Speed per min.	Screw Propeller diameter.	Indicated Horse-Power.			Steam Pressure.			Coal Consumption	
		Diameter.		Stroke.				High.	Low.	Total.	Boiler.	Mean Effective.		Per 24 Hours.	Per Ind. H. P. per Hour
No.	Class.	High.	Low									High cyl.	Low cyl.		
		Ins.	Ins.	Ins.	No.	Feet.	Feet.	H. P.	H. P.	H. P.	Lbs.	Lbs.	Lbs.	Tons.	Lbs.
1	A	42	75	42	47	329	17	373	420	793	58	27·0	10·3	24·5	2·80
2	A	45	80	36	51	306	15½	476	349	825	51	34·2	7·5	23·0	2·60
3	A	36	72	50	50	417	14¾	467	393	860	46	36·4	7·6	24·0	2·60
4	A	62	112	48	47½	381	18	787	665	1452	45	22·6	5·8	33·8	2·18
5	A	38	68	33	61	335	12	298	311	609	45	25·8	8·4	13·8	2·12
6	C	22	52	36	55	330	14	292	204	496	48	38·6	6·5	11·2	2·12
7	A	34	59	36	58	318	16	304	336	640	55	35·8	10·5	14·5	2·11
8	A	51	86	48	51	434	18	723	766	1489	49	26·9	10·0	33·2	2·08
9	A	46	80	39	65	422	14	527	710	1237	51	24·8	11·0	27·6	2·08
10	A	60	104	48	60	480	18	1027	1493	2520	52	25·0	12·1	55·8	2·07
11	A	41	70	39	70	455	15	361	525	886	58	20·8	9·6	19·5	2·05
12	A	46	82	48	54	432	17	761	633	1394	51	35·0	9·1	30·0	2·01
13	A	48½	84½	42	61	427	16	669	700	1369	55	28·0	9·6	30·0	2·00
14	A	34½	60	36	53	316	15	222	226	448	51	15·0	8·4	9·6	2·00
15	A	46	80	39	...	...	14½	...	...	...	50	...	...	19·4	1·99
16	A	36	72	50	52	433	14¾	457	401	858	54	34·2	7·5	18·0	1·95
17	A	26	52	36	51	306	17	153	211	364	53	31·0	10·7	7·6	1·94
18	A	44	78	42	57	399	15½	456	508	964	60	24·8	8·7	16·5	1·70
19	B	38	76	51	25½	216	Paddle	553	432	985	55	37·3	7·3	18·0	1·70

Average Consumption of Coal. Lbs. per Ind. H. P. per Hour. 2·11

Class A Compound Engines with one High and one Low-pressure vertical Cylinder, working two cranks at right angles.
B do. two " two " inclined " " two " opposite each other.
C do. two " two " vertical " " two " at right angles, cylinders combined, annular
E do. two " two " vertical " " two " do. do., high at top

TABLE II.

Boilers *of Compound Marine Engines.*

Engine No.	Number of Boilers.	Boiler Shell. Diameter.	Boiler Shell. Length.	Boiler Shell. Thickness.	Furnace Flues. Total Number.	Furnace Flues. Diameter.	Tubes. Total Number.	Tubes. Length.	Tubes. Diameter external.	Firegrate Area total.	Steam Pressure working.	Total Heating Surface. Tubes.	Total Heating Surface. Furnaces &c.	Total Heating Surface. Total.
	No.	Ft. Ins.	Ft. Ins.	Ins.	No.	Ft. Ins.	No.	Ft. Ins.	Ins.	Sq. Ft.	Lbs.	Sq. Ft.	Sq. Ft.	Sq. Ft.
20	6	14 3	10 4	·87	18	3 6	1260	7 5	3·50	315	60	8615	1986	10601
21	6	10 8	17 0	·87	24	3 0	1392	6 9	3·50	432	65	8602	1536	10138
10	3	12 3	16 0	·78	18	3 0	960	6 9	3·75	297	56	6355	1325	7680
4	8	12 0	8 0	·75	24	3 1	1392	5 6	2·75	333	50	5510	1745	7255
22	3	11 5	17 0	·75	18	2 10	1110	6 6	3·00	306	60	5661	1422	7083
23	3	12 3	16 0	·81	18	3 1	924	6 9	3·75	279	60	6122	856	6978
8	2	13 4	18 8	·81	12	3 3	840	7 6	3·62	228	60	5959	968	6927
13	2	13 3	18 0	·87	12	3 3	868	6 6	3·50	234	55	5060	1150	6210
12	2	12 7	17 1	·75	12	3 0	868	7 0	3·25	216	60	5164	902	6066
24	4	12 0	8 11	·75	12	3 0	876	6 0	3·00	180	60	4042	1026	5068
2	4	10×13½ft	9 5	·62	12	2 10	600	7 0	3·50	187	52	3850	1158	5008
3	4	10×13½ft	9 5	·62	12	2 10	600	7 0	3·50	187	54	3850	1158	5008
18	2	10 6	17 6	·69	8	3 3	816	6 4	3·00	182	60	4000	720	4720
16	2	12 3	17 6	·75	8	3 6	552	7 6	3·75	168	55	4067	575	4642
25	2	12 0	16 5	·75	12	2 10	576	7 0	3·50	170	60	3132	1191	4323
26	2	12 3	17 6	·75	12	3 1	480	7 6	3·75	185	54	3534	763	4297
1	2	13 1	10 7	·87	8	2 10	456	8 0	3·50	136	60	3342	726	4068
19	2	12 0	16 6	·75	12	3 0	472	7 0	3·75	180	55	3243	761	4004
15	2	12 0	12 0	·75	12	3 0	904	5 0	2·62	189	50	3104	526	3630
27	2	10 10	12 8	·75	8	3 1	768	5 2	3·00	120	64	3078	460	3538
28	2	10 6	15 0	·75	8	3 1	640	6 0	3·00	135	60	3014	475	3489
9	2	11 9	12 6	·75	12	2 10	816	5 0	2·62	170	56	2799	623	3422
7	2	14 3	9 3	·87	6	3 6	420	6 3	3·75	115	60	2557	603	3160
11	2	11 0	13 6	·75	8	3 0	568	5 6	3·25	114	60	2607	491	3098
14	1	13 6	15 9	·87	6	3 2	396	6 4	3·50	107	60	2268	427	2695
6	2	9×14 ft.	9 2	·56	4	3 3	324	6 6	3·50	76	65	1790	502	2292
5	1	12 0	12 0	·75	6	3 1	506	5 0	2·62	104	48	1738	289	2027
17	2	9 10	10 1	·62	4	2 11	268	7 3	3·25	66	50	1677	305	1982

TABLE III.

SURFACE CONDENSERS *of Compound Marine Engines.*

Engines No.	Engines Class	Cyls Diam. High	Cyls Diam. Low.	Stroke Length.	Revs. per min.	Indicated Horse-power working.	Steam Pressure working.	Condenser Tubes Number.	Condenser Tubes Length.		Condenser Tubes Diameter external	Condenser Tubes Space between	Total Condensing Surface	Circulating Pump Diameter.	Circulating Pump Stroke	Condenser Vacuum working
		Ins.	Ins.	Ins.	No.	H. P.	Lbs.	No.	Ft.	In.	Ins.	Ins.	Sq. Ft.	Ins.	Ins.	Ins. Mer.
20	A	56	97	48	...	...	60	2000	8	6	1·00	·75	4159	Centrifugal		25½
21	A	60	106	54	...	...	65	2419	15	6	·75	·37	7361	17 D	21 *D*	27½
10	A	60	104	48	60	2520	56	2257	14	1	·75	·35	6249	13½ D	26½ *D*	27¾
4	A	62	112	48	47½	1452	50	2415	14	1	·75	·35	6666	13½ D	32½ *D*	28
22	A	50	88	45	53	...	60	1706	6	7	1·00	·62	2934	26 S	22½ *S*	25
23	A	60	104	48	...	...	60	2256	14	0	·75	·35	6201	16 D	21 *D*	28½
8	A	51	86	48	54	1489	60	1759	8	6	1·00	·75	3911	Centrifugal		26½
13	A	48½	84½	42	61	1369	55	1725	13	4	·75	·37	4501	19½ S	16 *D*	28
12	A	46	82	48	54	1394	60	2304	6	9	1·00	·62	4078	26 S	25½ *S*	25
24	A	49½	86	45	...	...	60	1740	11	6	·75	·35	3929	20 S	21 *D*	27¾
2	A	45	80	36	51	825	52	4872	5	6	·56	·44	3944	36 S	24 *S*	26
3	A	36	72	50	50	860	54	2064	7	6	·75	·37	3040	30 S	25 *S*	26
18	A	44	78	42	57	964	60	1338	12	7	·75	·37	3250	18½ S	15 *D*	29
16	A	36	72	50	52	858	55	2064	7	6	·75	·37	3040	30 S	25 *S*	27
25	A	46	82	42	...	...	60	1228	11	6	·75	·35	2773	20 S	18 *D*	27
26	A	36	72	40	52	780	54	2064	7	6	·75	·37	3040	30 S	25 *S*	27
1	A	42	75	42	47	793	60	1797	6	0	1·00	·62	2821	26 S	21 *S*	26
19	B	38	76	51	25½ Pad.	985	55	1663	8	3	·75	·35	2694	16 D	20 *D*	27½
15	A	46	80	39	...	...	50	1292	10	10	·75	·35	2758	16 S	20½ *D*	28
27	A	39½	68	42	...	...	64	1170	9	9	·75	·35	2240	20 S	16 *D*	27
28	E	26 26	52 52	42	45	820	60	1900	6	3	·75	·50	2400	24 S	23 *S*	26½
9	A	46	80	39	65	1237	56	1289	10	10	·75	·35	2752	16 S	20½ *D*	27½
7	A	34	59	36	58	640	60	1342	7	2	1·00	·75	2573	Centrifugal		28
11	A	41	70	39	70	886	60	898	12	5	·75	·35	2189	14 S	17½ *S*	27
14	A	34½	60	36	53	448	60	890	7	9	1·00	·75	1811	21 S	36 *S*	27
6	C	22	52	36	55	496	65	608	7	10	1·00	·87	1246	22 S	18 *S*	26½
5	A	38	68	33	61	609	48	911	9	2	·75	·35	1654	13 S	15¾ *D*	28½
17	A	26	52	36	51	364	50	944	6	0	·75	·31	1112	20½ S	19½ *S*	27

NOTE.—Circulating Pump: Diameter—S single pump, D double pump; Stroke—*S* single-acting, *D* double-acting.

TABLE IV.

Steam Ships with Compound Engines.

No.	Ship.	Engine Makers.	When Started.	Voyage on which the results in Table I were obtained.
1	Persian	James Jack, Rollo, & Co.	Apl. 1871.	Mediterranean Coasting . Apl. 1871.
2	Bavaria	Day, Summers, & Co.	Mar. 1871.	Southampton and Hamburg . Mar. 1871.
3	Borussia	Day, Summers, & Co.	Apl. 1871.	Southampton and Hamburg . Apl. 1871.
4	Elbe	John Elder & Co.	Feb. 1870.	Southampton and St. Thomas Feb. 1870.
5	St. Clair	John Elder & Co.	Mar. 1868.	Leith and Aberdeen . May 1868.
6	José	James Jack, Rollo, & Co.	Sep. 1869.	West Indies . 1870.
7	Aracan	Denny & Co.	Dec. 1871.	Clyde and Rangoon . Dec. 1871.
8	Batavia	Denny & Co.	May 1870.	Clyde and Liverpool . May 1870.
9	City of London	John Elder & Co.	Aug. 1871.	London and Aberdeen . Aug. 1871.
10	Chimborazo	John Elder & Co.	Sep. 1871.	Liverpool and Valparaiso . Sep. 1871.
11	Cyphrenes	John Elder & Co.	Apl. 1872.	London and Port Said . Apl. 1872.
12	Holland	James Jack, Rollo, & Co.	Mar. 1870.	Liverpool and New York . Mar. 1870.
13	City of Bristol	Laird Brothers	Aug. 1871.	Liverpool and New York . Apl. 1872.
14	Amarapoora	Denny & Co.	Feb. 1872.	Clyde and Rangoon . Mar. 1872.
15	City of Rio de Janeiro	John Elder & Co.	Aug. 1868.	London and Brazil . Aug. 1868.
16	Danube	Day, Summers, & Co.	Dec. 1871.	Southampton and Cape Town Dec. 1871.
17	Sir Bevis	Day, Summers, & Co.	July 1871.	Middlesbrough and Varna . Oct. 1871.
18	Edinburgh	Laird Brothers	May 1870.	London and Malta . May 1870.
19	Arequipa	John Elder & Co.	Mar. 1870.	Callao and Payta . Mar. 1870.
20	Indus	Denny & Co.	May 1871.	
21	Spain	Laird Brothers	Aug. 1871.	
22	Istrian	James Jack, Rollo, & Co.	Apl. 1872.	
23	Garonne	Robert Napier & Sons	June 1871.	
24	Mendez Nunez	Robert Napier & Sons	Feb. 1871.	
25	Valdivia	Robert Napier & Sons	Sep. 1870.	
26	Syria	Day, Summers, & Co.	May 1871.	
27	Europe	Robert Napier & Sons	Sep. 1869.	
28	Neera	John Jones & Sons	Oct 1871.	

The PRESIDENT considered the paper now read was one of great value and interest, tracing as it did the important progress of improvements in the marine steam engine to the present time. The general result of those improvements was seen in the reduced consumption of fuel shown by the table accompanying the paper; the average consumption in nineteen vessels was here seen to be only 2·11 lbs. of coal per indicated horse power per hour. At the time of the previous meeting of the Institution in Liverpool in 1863, the consumption in the best marine engines he believed had been not less than $4\frac{1}{2}$ lbs.; the consumption had thus been reduced fully one half during the nine years which had since elapsed.

Mr. BRAMWELL drew attention to the circumstance that the figures given in the table of consumption of fuel were the results, not of trial trips, but of actual sea voyages; and the mean average of the nineteen vessels being as low as 2·11 lbs. of coal per horse power per hour, the highest consumption was seen to be only 2·80 lbs., while the lowest was not more than 1·70 lbs. The consideration of this table in comparison with the condition and economy of marine engines ten years ago appeared to him to justify the hope expressed by the President that in the course of another ten years another 50 per cent. of saving in consumption of fuel might be realised.

Mr. J. L. K. JAMIESON said he had had great pleasure in listening to what had been urged in the paper in favour of the use of compound engines for marine purposes, having himself had charge of the erection of the first pair of altered compound engines on MacNaught's plan in 1848 at Messrs. Johnstone and Galbraith's Spinning Mills in Glasgow, and being also connected with Messrs. Randolph and Elder, who made the first compound marine engines supplied to the Pacific Steam Navigation Co., since which time they had erected more than one hundred marine engines of that class. There was no doubt that great improvements had been made since the construction of those first compound engines; at the present time the compound marine engines were doing double the duty with the same amount of fuel as ten years ago; and the present engines made by his firm with two pairs of compound cylinders

were working with one third the fuel that was used in 1855 by ordinary single-cylinder engines. The voyage to Valparaiso and back consumed at that time from 1080 to 1200 tons of coal; the same ships with the improved engines did the same distance with 550 to 600 tons; while larger ships of more recent construction performed the voyage with 350 to 400 tons of coal, and at a greater speed. Whatever might be the future of the marine engine, great progress had been made within the last ten years, and even within the last five years. Although it appeared to be considered in the paper that the same amount of expansion and of economy might be obtained in single-cylinder engines as in compound, yet the fact was that there had been no instance, so far as he knew, of single-cylinder marine engines proving commercially successful; notwithstanding the excellent results obtained from the single-cylinder engines tried by Mr. J. F. Spencer with 50 lbs. steam, he understood these had been given up, though he did not know the reason. The compound engine was the one almost universally employed at the present time for marine propulsion; and if further improvements were made in it and in the boiler connected with it, important results would be achieved. Improvement of the boiler should now receive special attention, with the object of obtaining a further reduction in the consumption of fuel for generating the steam. If it could be managed to evaporate twice as much water with the same amount of fuel, by forced combustion and by generating the steam in smaller tubes, a great end would be accomplished; he had no doubt this would ultimately be effected, and he hoped that during the next ten years the consumption of fuel per horse power per hour would be further reduced in as great a proportion as it had been during the last ten.

Mr. W. Thompson said he had had some experience with single-cylinder marine engines working in pairs with a high rate of expansion in each cylinder; and the reason they had been given up was that it was found the working parts could not be got to stand, owing to the constant shock at the beginning of each stroke, and especially the valve-gear could not be made to stand for any length of time the heavy strain under which it had constantly to work. There was

a cut-off slide on the back of the main slide-valve, both being of cast iron, cutting off at 1-5th to 1-6th of the stroke, with steam at 40 lbs. pressure; but however strong the valve-gear and parts were made, they ultimately gave way, and no long voyage was made without a failure at some part or other. So long as the vessels with the single-cylinder engines were confined to short voyages, such as those of not more than about twenty days to the Mediterranean ports, the difficulty was not serious; but in longer ocean voyages, such as those of thirty or forty days, the engines would not stand the work. It might also be mentioned that Mr. William Horn, the engineer of the St. Petersburg Steamship Co., who had been one of the foremost in endeavouring to economise fuel in marine engines, had given up single-cylinder engines as soon as the compound engine was introduced, and had replaced with compound engines many of the single-cylinder engines that he had put into the steamers under his charge, besides adopting the compound principle for all the later engines. Instead of coupling the two cylinders of a compound engine to cranks at right angles, he had himself found it preferable to place the cranks at 120°; the engines then gave a better diagram, and they worked evenly and well.

The PRESIDENT enquired whether the double-beat valve had been tried for single-cylinder marine engines.

Mr. W. THOMPSON replied that he had not tried the double-beat valve; but the Corliss valve, which had been tried for the purpose by Mr. Spencer, had given as much trouble as the ordinary slide-valves.

Mr. BRAMWELL enquired whether it was the gear of the main valve or of the expansion slide that gave way under the strain of working; he supposed the former would be the more likely to fail, owing to the increased friction thrown upon the main valve by the expansion slide at the back of it.

Mr. W. THOMPSON replied that it was the gear of the main valve which had failed. The difficulty had been so great that in several vessels the expansion slide had been taken out, so as to relieve the main valve of the extra friction, and the single-cylinder engines had then been continued to be worked with only an ordinary single slide-valve.

Mr. R. H. Humphrys mentioned that the Peninsula and Oriental Co. had still several vessels running with single-cylinder engines, having an expansion slide on the back of the main valve. The original single-cylinder engines in the "Mooltan" had been replaced by compound engines simply because they had not been constructed of sufficient power to drive the ship at the speed desired. In other cases of single-cylinder marine engines there had been trouble in consequence of the boilers not being made with sufficient heating surface to supply steam enough; but since new boilers of greater power had been put in, there had been no further trouble, and the single-cylinder engines had been as successful as any of the compound engines.

Mr. T. R. Crampton thought that in all questions of economy of steam engines it was important for the engine duty to be considered separately from that of the boiler, by ascertaining how much water was used by the engine in the form of steam for doing a certain amount of work, independent of the evaporative effect obtained by the boiler from the fuel consumed. The economy to be realised from higher pressures of steam with greater expansion was a subject upon which he had made experiments thirty years ago in conjunction with the late Mr. Humphrys; and the conclusion he had then arrived at was that scarcely any advantage was gained by going beyond about 30 or 35 lbs. steam pressure above the atmosphere, and a moderate expansion of five or six times. The experiments upon this point had been made with a single-cylinder pumping engine, 18 inches diameter and 20 inches stroke, pumping water from a well of 180 feet depth by means of a double-acting pump placed at the bottom of the well, by which the water was delivered into a tank at the surface. The engine was jacketed, and had an ordinary slide-valve with back cut-off slide for expansion; all the other steam surfaces were carefully protected, and surface condensation was employed; the pump rods were worked from a crank on the shaft of a heavy flywheel driven direct by the engine, and the weight of the rods was counterbalanced by a counterpoise. The steam pressure first employed was 70 lbs. above the atmosphere, with an expansion of twelve times, and was reduced 10 lbs. at a time in successive weeks,

until the pressure was only 35 lbs. with an expansion of six times. The result obtained was that, although the indicator diagram showed the theoretical gain, the consumption of fuel continued practically unaltered for the water lifted, notwithstanding the reduction of pressure; it amounted to about $2\frac{3}{4}$ lbs. of coal per horse power per hour, when the power was estimated by measurement of the water actually raised, and $2\frac{1}{4}$ lbs. per indicated horse power. In explanation of this result it should be borne in mind that the theoretical gain in using steam say of 100 lbs. total pressure above a vacuum and expanding twelve times, as compared with 50 lbs. steam above a vacuum and only six times expansion, did not exceed about 20 per cent., which he considered was probably quite neutralised by the increased condensation in the cylinder and steam jacket, boiler and other surfaces, and by the increased friction of the engine when using the higher pressure of steam. The steam jacket of the cylinder in the experiments had been well drained, and the water drawn off from it had been measured and found to be considerably greater at the higher steam pressures. The practical result arrived at in these trials had therefore been that, with the same evaporation from the boiler, the same quantity of water was raised by the pump when working with 35 lbs. steam above the atmosphere, expanded six times, as when 70 lbs. steam was used with twelve times expansion. He was accordingly convinced that no appreciable good would result, even in the economy of fuel, from the use of the high pressures and high degrees of expansion commonly advocated; but when the extra first cost of engine and boilers and the increased wear and tear were taken into account, the commercial result would be in favour of the lower pressures; and instead of marine boilers having to be constructed of $1\frac{1}{8}$ inch plates, as at present, for carrying pressures of 80 to 100 lbs. per inch above the atmosphere, further experience he believed would result in the adoption of not more than 40 lbs. as the best commercial limit of boiler pressure, with $\frac{5}{8}$ inch plates. The objection sometimes urged to the employment of high pressures, on account of the shock produced at the beginning of the stroke by the steam being admitted at full pressure upon the piston, was one which did not seem to

him to be of practical importance; it was only necessary to take care that there was a sufficiently large mass of matter in the reciprocating parts, in which case no shock would occur in starting them into motion. In the experiments with the pumping engine that he had mentioned, the flywheel shaft working the pumps made 30 revolutions per minute, and scarcely any variation in the speed of the flywheel could be observed, the sudden blow upon the piston at the commencement of each stroke with the high pressure of steam being absorbed by the inertia of the great mass of matter in the pump rods and counterpoise, which had to be put in motion from a state of rest. There was therefore in effect nothing that could be called a blow upon the piston from the high-pressure steam, nor could any such cause be assigned in that case in explanation of the fact that the theoretical saving due to the higher pressure and higher expansion was not realised in practice. With the moderate pressure and expansion which he believed to be practically sufficient, no compound-cylinder arrangement would be required, as single-cylinder engines having the steam cut off by a common slide-valve with the ordinary link-motion worked well; by this means too he thought a better indicator diagram would be obtained than those exhibited from the present compound engines.

Mr. J. McFarlane Gray was glad to find that the views expressed in the paper and illustrated by the diagrams agreed with the conclusions he had himself arrived at from carefully investigating the subject of uniformity of tangential force in marine engines throughout the different portions of the revolution of the screw propeller. The actual irregularity in the rotary motion was somewhat less than that due to the variation of tangential force, because the weight of the revolving parts acted as a flywheel; but their radius of gyration was not great, and their momentum generally was insignificant in comparison with that of the ship itself. Taking the case of a vessel of 3,000 tons displacement, moving at the rate of 10 knots an hour, and propelled by a screw of 25 feet pitch running at 50 revolutions per minute, he had calculated that

the total moving force in the mass of the vessel would amount to as much as the whole power given out by the engines during 92 revolutions. A variation of the tangential force during a small portion of one revolution could make therefore but a slight variation in the speed of the ship; and if this variation of tangential force were an excess of pressure acting during one quarter of a revolution with a force one half more than the average, the vessel would move only 1-15th inch more than its average in that time.

The loss of power however by slip of the screw was increased by irregularities in the driving force, the slip being thereby rendered irregular. The loss of power was proportional to the cube of the slip, while the useful effect varied as the square of the slip; and it followed therefore that if during equal portions of time at different parts of the same revolution the slip were respectively 40 and 20 per cent. of the advance of the vessel, giving a mean of 30 per cent., the useful effect would be equal to that produced by a uniform propelling power with a uniform slip of $31\frac{1}{2}$ per cent., but the loss by slip would be 36 per cent. of the useful effect. To reduce this irregularity and consequent loss, flywheels had been added to single-cylinder marine engines, and in practice it was believed a very considerable gain was thereby effected; this might be due not only to the flywheel equalising the motion in different parts of the same revolution, but also to its acting as a governor to equalise the motion during the longer periods of pitching.

With regard to the transverse strain thrown upon the screw shaft by the gyroscopic action of the flywheel when the vessel was pitching, about which some apprehension had been felt, the compound engines for some new ships now building, with single crank and flywheel on Mr. Holt's plan, had each a flywheel 12 feet diameter with a rim of 7 tons weight, and the number of revolutions would ordinarily be 60 per minute. In case of the engines racing, so as even to double the number of revolutions per minute, and supposing the pitching of the ship to give a transverse motion to the flywheel rim at the rate of even one foot per second, yet the transverse strain thereby thrown upon the screw shaft would only be equal, he calculated, to the weight of the flywheel acting with a

leverage of one foot; this strain would accordingly be inappreciable in effect.

With regard to the loss of power in a compound engine by the expansion of the steam into the intermediate reservoir between the high-pressure and low-pressure cylinders, this could be greatly reduced by having the high-pressure cylinder so large that the steam should be expanded in it down to nearly the initial pressure of the low-pressure cylinder; and also by cutting off earlier in the low-pressure cylinder, so that the minimum pressure in the reservoir should be increased, and the initial pressure in the low-pressure cylinder also thereby raised. In this way the engines constructed by Messrs. Randolph and Elder had at an early date been made to have but little loss in the reservoir. One important point in the economy of marine compound engines was to have the high-pressure cylinder large enough to be able to use all the steam the boilers could make when working at as low as 30 lbs. or even only 20 lbs. pressure. If this were not attended to, it would happen that when the pressure had to be reduced, owing to the wear of the boilers, from 70 lbs. to say 30 lbs. pressure, the engine would not be able to use all the steam the boilers could make, and the speed of the vessel would consequently be much reduced; whereas if the high-pressure cylinder were large enough, the horse power would be nearly the same, and even the loss of economy would not be so great as to require the immediate renewal of the boilers. The screw steamer "Colleen Bawn" running between Dublin and Liverpool, with compound engines by Messrs. Randolph and Elder, had for many years not had more than 20 or 22 lbs. boiler pressure, and with that pressure the economical result had been highly satisfactory to the owners; and when recently getting a new steamer, they had ordered it with compound engines, although their experience of compound engines had been gained in working with only so low a pressure.

The opinion already expressed about the limit of steam pressure in engines was one with which he concurred, as he considered the ultimate economical limit in compound marine engines had

been reached, and had even been exceeded. He believed that 60 or 70 lbs. was as high a pressure of steam as could be advantageously employed at sea, because at higher pressure the increase in economy would be at a much slower rate; and the endeavours to work with higher pressures appeared to originate in an erroneous opinion respecting the benefit of expansion, that increase of pressure was necessarily productive of a proportionate increase in economy. With the higher pressures now in use in marine engines he thought it was important to consider whether the construction of the boilers and the thickness of the plates were such as to render them really safe in working. He was glad to hear that the priming in compound engines was found to be reduced with the increase of steam pressure, though his own experience had been very different in this respect.

One name to be remembered in connection with the introduction of compound marine engines with two cylinders working cranks at right angles was that of Mr. William MacNab, of Greenock, who introduced engines of that description before 1860; and also three-cylinder engines working three cranks at 120°, the high-pressure cylinder expanding into the two others.

Mr. Jeremiah Head thought one very important improvement still to be made in connection with the working of marine engines was the adoption of some mode of mechanical firing for the boilers, to obviate the present employment of hand labour for the purpose, the work being of so severe a character that it was with the utmost difficulty the men could stand it for the requisite length of time, exposed as they were to the heat of the furnaces in the stoke holes; and the labour was greatly aggravated when it had to be performed in a tropical climate. With ample steam power close at hand, it remained only to devise suitable mechanical arrangements; and the object to be accomplished appeared to him to be far easier than many others which had already been successfully effected by mechanical means.

The President remarked that the subject of mechanical firing for steam boilers generally was one of so much importance as to require a separate discussion; and he trusted the application of some

plan for that purpose, or of a plan of firing by gas produced from imperfect combustion of the fuel in a separate chamber, would not be lost sight of in the case of marine boilers. The opinion which had been expressed, that no advantage was to be gained in marine engines by employing a higher pressure of steam than about 35 lbs., was one that would take many by surprise; and he should be glad therefore to hear some statement of the actual results that had been obtained where higher pressures of steam had been adopted.

Mr. J. L. K. Jamieson mentioned that the original pressure of steam in the compound engines of the "Valparaiso" by Messrs. Randolph and Elder, referred to in the paper, was 25 lbs. per square inch; the cylinders were 50 and 90 inches diameter, and were not steam-jacketed except at top and bottom; the piston speed was from 230 to 250 feet per minute, and the indicated horse power was under 900. The next set of engines were made exactly of the same size and worked with the same pressure of steam; but the cylinders being completely jacketed, the indicated horse power rose to 1150. Two other sets made from the same patterns had larger condensers and better air-pumps, and the steam pressure was raised to 30 lbs., the result being 1200 indicated horse power. In 1860 they had adopted surface condensers; and a pair of engines then constructed with 48 and 93 inch cylinders, working with 40 lbs. steam, gave 1450 indicated horse power. Several sets of engines of the same size worked with a pressure rather above 40 lbs., raising the indicated horse power to 1560. In the engines of the "Arequipa" and other ships, which had only recently been erected, the cylinders were 38 and 78 inches diameter with 60 lbs. steam, and the indicated horse power was 1720. It was thus seen that by the use of the higher pressure of steam the indicated horse power with these smaller cylinders had been nearly doubled in comparison with that obtained from the original 50 and 90 inch cylinders working at the lower pressure of 25 lbs. At the same time the consumption of coal had been reduced in the present engines with the 60 lbs. steam to only one half of what it had been in the original engines with the 25 lbs. steam. Unless the pressure of steam had been increased, it would have been necessary to have very much larger cylinders for

obtaining the increase of power; but there were practical limits to the size of the cylinders, and it was therefore a great advantage of the high-pressure steam, independent of the saving of coal, that it afforded the means of obtaining much greater power from the engines, while actually reducing considerably the size of the cylinders. His own experience had thus been that there were important practical advantages in the increase of steam pressure which had taken place in marine engines up to the present usual pressure of about 60 lbs.; with this pressure he thought it might be well to rest satisfied for a time, until it had been sufficiently ascertained how any further increase of pressure could be successfully dealt with.

Mr. T. R. CRAMPTON agreed in the necessity of having recourse to higher pressures of steam in cases where it was requisite to employ smaller cylinders; but such a step was one which he thought should not be taken if it could be avoided, the lower pressure being in his opinion preferable for obtaining the highest duty from the steam. With regard to the question of steam-jacketing the cylinders, he had made some experiments in connection with Mr. Humphrys about fifteen years ago upon a factory engine which still continued at work. It was a compound engine, the low-pressure cylinder being about four times the capacity of the high-pressure; and both cylinders were completely jacketed all over, the jackets being supplied with steam at full boiler pressure; means were also provided for disconnecting the low-pressure cylinder, and using the steam in the high-pressure cylinder alone, exhausting then from this cylinder direct into the condenser. The engine was first tried with both cylinders in action, and with a total expansion of about six times, but without any steam in the jacket. On then admitting steam to the jacket, the power was nearly doubled, with the same cut-off in the high-pressure cylinder. On disconnecting the low-pressure cylinder and using the high-pressure cylinder alone, with the same cut-off but without the steam-jacket, the work done was exactly the same as had been performed by the pair of cylinders in conjunction when working without the steam-jacket: thus showing that the loss by condensation in the low-pressure cylinder without the jacket was just equal to the value of the expansion effected in that cylinder. When the steam-

jacket was applied to the high-pressure cylinder working as a single cylinder, the power obtained was nearly doubled. A moderate superheating of the steam was then tried, both in the cylinders and in the jacket; and the gain thereby obtained was about 12 per cent. From practical experience of superheating however, Mr. Humphrys had ultimately come to the conclusion, with which he himself agreed, that it was not really advantageous, because if the steam were superheated beyond a certain moderate limit many inconveniences arose; whereas on the other hand the slight condensation occurring in the cylinders when the steam was not superheated acted beneficially as a lubricator.

Mr. W. Thompson stated that in the instance of a compound marine engine, having the cylinders steam-jacketed and the steam cut off at one third of the stroke and expanded about twelve times, the superheating of the steam, which had originally been adopted, had afterwards been given up without causing any loss of effect. To simplify the engine, the expansion valve had also been abandoned and the steam cut off at half stroke by a single slide-valve, when the engine still worked as economically as before. The steam-jacket of the low-pressure cylinder was next given up, and was not missed, the same work being got out of the engine with the same consumption of coal. A practical objection to the use of a steam-jacket was the difficulty of casting the cylinder with the jacket so as to ensure a thoroughly sound casting. In a recent instance of a vessel having a compound engine with only the high-pressure cylinder steam-jacketed, this cylinder had become cracked at the lower end during the outward voyage to India, and on her return home he had put in a new high-pressure cylinder without a steam-jacket; the vessel was now at Malta, and he was informed that the voyage there from England had been performed at the same speed and with the same consumption of coal as when the steam-jacket had been in use. Having previously given up the steam-jacket of the low-pressure cylinder, he had now come to the conclusion therefore that that of the high-pressure cylinder could also be abandoned without any diminution of economy or speed.

Mr. E. R. Allfrey mentioned that in the compound engine at Messrs. Humphrys' works, to which reference had been made, it had been found that when the steam was shut off from the jackets of the cylinders the speed fell from 120 revolutions per minute to about 85 revolutions. This experiment had been repeated several times, and always with the same result.

Mr. C. F. Gurden considered that, independent of the question of economy of fuel, the efficiency of the engine was of great importance to the owner, certain designs of compound engines especially doing apparently more work than a pair of single-cylinder engines of the same indicated horse power, on account of the angular velocity of the shaft being more regular during its revolution with the compound engines. This was the conclusion he had come to from experience of the actual working of engines of both descriptions. In the case of two vessels of nearly the same size, he had found that the larger, having a compound engine working at a certain power, was driven at a higher speed than the smaller vessel with a pair of single cylinders indicating considerably more horse power. In another instance where a compound engine had been substituted for the previous single cylinders in the same ship, the indicated horse power obtained from the compound engine was less than before, but the ship was driven at a slightly greater speed, showing that the tangential force exerted on the crank by the compound engine was more regular throughout the revolution. The case was similar to that of attempting to push a railway truck along by a succession of jerks, which would not be so effective in moving it as a continuous steady pressure. This question of the efficiency of the engine was one depending more upon the style and arrangement, and also upon the number of revolutions per minute and the weight and balance of the revolving parts, than upon the engine being simple or compound, as he had found certain forms of compound engines to be worse in this respect than single-cylinder engines. The general result he had found to be that for the same speed of ship a saving of about 10 per cent. was effected in the indicated horse power of the engines, by the substitution of the compound arrangement.

The working of the circulating pumps for the surface condensers was a point requiring attention in marine engines, and he had found that a material proportion of the power developed by the engine was expended in this way, especially when a single-acting reciprocating pump was employed. In a case that had come under his notice of a reciprocating circulating pump, which had afterwards been replaced by a centrifugal pump, the power expended in working the reciprocating pump had been as much as 37 horse power, merely for forcing the water through the condenser tubes, without including the friction of the pump itself and the levers working it, which would have raised the power to about 50 horse power. When the centrifugal pump was put in, it required only 10 horse power for doing the same work, including the friction of the pump. In another instance the circulation of the water through the surface condenser had been effected without any pump at all, by simply making a hole in the ship's bottom and fitting it with a sort of scoop projecting forwards, so that the motion of the vessel caused a current of water to enter and pass up through the condenser, the top of which was just below the level of the ship's water-line, and had a discharge pipe at that level; the heating of the water in its passage through the condenser also augmented the force of the upward current, in consequence of the water becoming lighter as it got hotter. With this arrangement a vacuum of 20 inches of mercury was maintained in the condenser. It would appear therefore that there was great room for saving in the working of the circulating pumps of large marine engines.

Another point connected with the economy of marine engines was the provision and proper use of a damper in the funnel, so as to utilise the greatest possible amount of heat from the coal consumed. From experiments that he had made with marine boilers fitted with a damper, he had found that when working the engine at full power and with the damper full open the indicated horse power was 1200, and the consumption of coal was 2·0 lbs. per indicated horse power per hour, care being taken to burn all the coal thoroughly without wasting it; but with the damper partially closed and the engine indicating 1000 horse power with the expansion link

in full gear, the consumption was reduced to 1·7 lbs., the saving of fuel being thus in a greater proportion than the reduction in power. When the damper was further closed for driving the engine at half speed, the consumption was still further reduced. By the use of a pyrometer in this case it was found that, when the damper was one third open, the temperature below the damper, surrounding the superheating steam-chamber in the smokebox of the boiler, was about 750° Fahr.; but above the damper the temperature of the waste heat escaping up the funnel was only about 500°. If however the damper had been full open, as it was when the engine was indicating 1200 horse power, the temperature would have been the same above it as below; the difference between 750° and 500° would therefore represent so much greater loss by escape of waste heat when the damper was full open, and this showed how much greater economy could be obtained by proper attention to the working of the boilers. It was also found that the difference shown by the pyrometer between the temperatures above and below the damper when partially closed was much greater on leaving port, when the boiler surfaces were clean, than after the ship had been some days at sea: leading to the conclusion that if by any process the boiler flues could be kept clean, considerable economy would be effected.

Mr. W. Laird thought the economical results given in the paper which had been read illustrated clearly the great commercial advantage derived from the adoption of compound marine engines. His own firm having been engaged for many years in the construction of marine engines had of late made none but compound engines, which he believed to be commercially the best. This class of compound engine was illustrated in the drawings exhibited, consisting of one high-pressure and one low-pressure cylinder working cranks at right angles. An opportunity had been afforded for ascertaining the economy of compound engines as compared with single-cylinder engines, in the case of a vessel originally fitted with single-cylinder engines and refitted with compound engines; the practical results of working were found to be that the

quantity of coal consumed per indicated horse power per hour under the compound system was only about half what it had been with the previous engines. The use of the compound engine for marine purposes had been of the greatest benefit to commerce, from the very large saving thereby effected in coal; the various steamship companies now extensively adopted this system, in all cases for their new vessels, and in some instances for refitting their old vessels. With regard to the pressure of steam that was found most advantageous, 60 to 70 lbs. as already mentioned was the pressure which marine engineers now understood how to provide for, and this was the general pressure adopted in steamers sailing from Liverpool. Speaking generally of the successful adoption of compound marine engines, he felt satisfied that to revert to a lower steam pressure and engines on the old system would be going backwards, and would be a very great mistake.

Mr. E. R. Allfrey mentioned that an illustration bearing upon the comparison between compound and single-cylinder engines, which gave a different result from that previously named, was furnished by two screw steamers built at Pembroke, the same in every respect, loaded up to the same draft of water, and fitted with boilers exactly the same. One of them, the "Swinger," had a pair of single-cylinder engines with expansion valves, working cranks at right angles; and the other, the "Goshawk," had a compound engine with cylinders working cranks at right angles. Both vessels were tried the same day, and ran alongside each other throughout the six hours' trial, with the same consumption of coal, and the indicated horse power was very nearly the same; if anything slightly in favour of the single-cylinder engines; the steam pressure was 60 lbs. in both engines.

Mr. T. R. Crampton enquired what had been the condition of the old single-cylinder engines which had been referred to as having been replaced by compound engines with so much advantage. If the old engines were of an inferior description and were replaced by good compound engines, he did not think a fair comparison would be obtained.

Mr. W. Laird replied that the single-cylinder engines which had been superseded by a compound engine in the instance he had alluded to had been good engines using 20 lbs. steam, with an injection condenser, but without steam-jackets to the cylinders. Admitting that in particular cases of the removal of single-cylinder engines there might have been circumstances giving an advantage to the new compound engines, his object had been simply to call attention generally to the benefit derived from the introduction of compound marine engines, and to the degree of perfection to which they had now been brought. The result that he had mentioned as to economy of fuel was not based upon a solitary instance, but there were several cases which would bear out the statement that the consumption of coal had been reduced one half by the substitution of compound engines for the previous single-cylinder engines, though the latter had been of the best modern construction and in good working order.

Mr. C. F. Gurden mentioned, in reference to the comparison between compound and single-cylinder engines, that some of the most economical single-cylinder marine engines with which he was acquainted were those in vessels belonging to a Russian company and running between London and the Black Sea. They were made by Messrs. Penn and Messrs. Maudslay, and worked with about 30 lbs. steam cut off at one sixth to one eighth of the stroke, having steam-jacketed cylinders, with surface condensers and superheaters. The consumption of coal was never below 2 lbs. per indicated horse power per hour, and was generally above $2\frac{1}{4}$ lbs. Few engineers however would be satisfied with such a consumption of fuel, as by using well designed compound engines the consumption was reduced below 2 lbs. per indicated horse power per hour.

Mr. J. Ramsbottom observed that the question of the economy to be derived from increased steam pressure and greater expansion was practically a commercial one; but as regarded the abstract view of it, there were hardly two opinions, as it was admitted on almost all hands that advantage was to be obtained from an increased pressure and an earlier cut-off, and whether the expansion were conducted in one or two cylinders was theoretically a matter of little consequence.

But when it came to practice, there were great discrepancies between the views which had been advanced upon the subject. The balance of evidence appeared to himself to advance with theory, and to establish the conclusion that the higher the pressure of steam and the earlier the cut-off, the greater was the economy in the use of the steam, within certain practical limits assigned by engineering and commercial considerations. In the case of railways, the pressure employed in the earlier locomotives had been only 50 lbs., but was now nearly three times as great, and a steady increase of mechanical effect and economy had attended the rise of pressure. It did not follow that the limit, as regarded the commercial results, had not yet been reached; but at the present time the question was whether materials could be got or modes of construction adopted which would prove superior in strength and durability to those now employed; if not, the practical limit of commercial economy must be considered to be already pretty nearly reached in locomotives, and he presumed also in marine engines. At the present time it was more particularly the boilers upon which the prospects of using steam at higher pressures depended. He did not think it was likely the pressure employed would be reduced much below what it had now risen to, and he should be glad to be able to see that it was likely to be increased. If a material could be found which would resist the strain and the temperature combined, the best mode of construction would no doubt also be found out, and higher pressures than the present might be looked forward to, with corresponding economy.

With respect to the trials of engines for speed and economy, he considered isolated experiments of a few hours or days were as a rule of very little value. A hot bearing or a leaky joint or the mere excitement of the trial itself might lead to conclusions not at all corresponding with the facts; and on this account speed mile trips in particular, however carefully conducted, appeared to him of very little practical value. The truest and safest results he thought were those based upon actual sea voyages of great length, in which all errors arising from exceptional causes were eliminated, as in the case of the results given in the table accompanying the paper.

Mr. BRAMWELL thought a tone of finality, such as had characterised some of the remarks made in the discussion, was a dangerous one for mechanical engineers to assume; and he quoted several instances of the mistaken conclusions to which it had led many eminent engineers to commit themselves in earlier periods of mechanical progress. In 1817 a parliamentary commission had been appointed in consequence of the explosion of a boiler using high-pressure steam on board a steamship at Yarmouth; the boiler was a cylindrical vessel of wrought iron, but one of the ends had been replaced by a flat cast-iron one, which gave way. The opinions expressed by several eminent engineers then examined were to the effect that the limit for steam pressure in boilers should not exceed $2\frac{1}{2}$ to 6 lbs. above atmosphere, and that there was no saving to be effected by employing a higher pressure. Also that cast iron was preferable to wrought iron for the construction of the boilers, as more free from leakage, and capable of being made stronger, because the metal could be much thicker than plates of wrought iron; that if wrought-iron plates were used they should be hammered and not rolled; and that wrought-iron boilers were difficult to keep joint-tight at a higher pressure than 10 lbs., and were consequently useless for high steam. Again in 1839, in a parliamentary enquiry on steamboat accidents, it was stated by eminent marine engineers as the result of experience, that there was no economy in working a marine engine with high-pressure steam, and that, although rather more effect might thereby be obtained from an engine of the same weight, this would be accomplished at a great sacrifice of fuel. Another practical opinion given on the same occasion was that it was not possible to construct high-pressure marine boilers which should be of reasonable utility and duration and at the same time not be liable to explosion. These quotations from the opinions of some of the most eminent of our predecessors, showing that in their judgment perfection had been reached half a century ago, would he thought serve to point out the danger of attempting to assign any permanent limit to the progress of improvements in any branch of mechanical engineering.

With regard to the opinion which had been expressed that not much reliance could be placed upon mere trial trips, and that the results obtained in the course of long voyages were preferable, he should agree with this view, were it not a steamboat that had to be tried. But looking at the fact of the great reduction in horse power consequent upon a small reduction in the speed of a ship,—as illustrated in the trial of the "Briton," referred to in the paper, which had indicated 2018 horse power at the full speed of 13 knots per hour but only 660 horse power at 10 knots,—it was evident that any error in taking the indicator diagrams would seriously affect the result over a long voyage; and he considered therefore more reliable results were likely to be obtained in a trial, though extending over a period of only six hours, because such a trial would be conducted with every care and no untrue diagrams would be taken. Such a trial showed indeed what the engines could do in the way of economy, not necessarily what they would do in actual working; and the only means that he knew of for arriving at the real economy throughout a voyage was by the employment of a continuous indicator, such as the one of which a description had been given at a previous meeting (see Proceedings Inst. M. E. 1871 page 75). This instrument he hoped would be generally adopted for marine engines, as it gave an absolute record of the total horse power exerted throughout the entire voyage, which had then only to be divided by the total consumption of coal in order to obtain the true consumption per horse power, free from all liability to the errors arising from accidental circumstances, that would interfere with the accuracy of the results derived from indicator diagrams taken only at intervals.

Upon the question of expansion in single or in compound cylinders, he had not yet been able to come to a decided conclusion in favour of either system in preference to the other, and had therefore not attempted to do more than bring the subject forwards for consideration and discussion; but he was inclined to think on the whole that the compound cylinders had the advantage. From the information however which had been furnished by Mr. Allfrey regarding the comparative trial of the two plans, it appeared that the question still remained an open one.

With respect to the diminution of priming in high-pressure boilers, he hoped he had not been misunderstood as stating that priming would be entirely prevented by the use of high pressures of steam; his remark pointed to this fact, that there would be less agitation of the water in raising a certain weight of steam in a given boiler at say six atmospheres pressure than at three atmospheres, and that therefore the liability to priming would be diminished. As a practical proof of this, the meeting might be reminded that when a boiler was found to be priming, it was usual partially to close the regulator immediately, for the purpose of increasing the pressure in the boiler and thus checking the carrying over of the water by the steam. The reason was that at the increased pressure the bubbles of steam were of smaller size, and the water was consequently not so much disturbed in giving them off; there would therefore be greater freedom from priming in the use of a given weight of steam at high pressure than with the same weight of steam generated during the same time at a lower pressure.

In reference to the difficulty which had been alluded to of working the main slide-valve with the expansion slide on the back of it, in consequence of no plan being entirely successful for taking the whole of the pressure off the back of the valve, it must be borne in mind that, whatever friction there was when the main valve was worked alone without the expansion slide, this friction was nearly doubled in amount by the addition of the expansion slide on the back of the main valve, owing to the additional rubbing surface between the two valves. This principle of increasing the total friction by increasing the number of rubbing surfaces under the same pressure had been taken advantage of in the construction of a friction coupling and break described at a former meeting (see Proceedings Inst. M. E. 1868 page 214). He did not think however that mechanical difficulties with the valve gear should prevent the employment of expansion; rather than do this, it would be better to resort to the American river-steamer plan of drop-valves in lieu of slides.

Attention had been called in the discussion to that which appeared to lie at the root of further economy, namely a greater evaporative

duty from the fuel consumed; and for the attainment of this object he fully agreed in the desirability of mechanical stoking, which was a problem that he thought ought to be solved. If this were accomplished, far greater regularity of combustion would be obtained, and consequently the fuel would produce a far better effect. With the hand stoking in the trials of portable engines by the Royal Agricultural Society, as many as thirty to forty-five firings in an hour were made, instead of only four or five per hour prescribed by the old rule; and although it was objectionable for a firedoor to be so frequently opened, yet the firing was done with such rapidity that the firedoor was not open for more than an instant at each firing, and thus the total time of the door being open was no greater than formerly. By this frequent and skilful firing a uniformity of effect was thus obtained which could scarcely be exceeded by an efficient mechanical apparatus; and the result had been that from 10 to 12 lbs. of water were evaporated per lb. of Welsh coal in the trials at the recent Cardiff meeting.

With regard to the effect of the high initial pressure of the steam in an engine working with a high degree of expansion, he had ascertained that in the case of a compound engine with 60 and 106 inch cylinders the weight of the piston and the rest of the moving parts belonging to the high-pressure cylinder was equal to a pressure of 6 lbs. per square inch on the piston. For an engine making 90 revolutions per minute, he calculated that it would take about 24 lbs. pressure per square inch on the piston to overcome the inertia of this weight and start it into motion at the speed required. This 24 lbs. per square inch had consequently to be deducted from the initial steam pressure, leaving only the remainder for producing tangential force at the crank; and there seemed no reason therefore to fear that the use of a high initial pressure would produce any effect of a blow at the commencement of the stroke.

The President thought it might be gathered from the remarks in the discussion that marine engineers at the present time understood full well the advantages of using steam at high pressure, with an early cut-off, and as perfect condensation as could be

obtained. Although it was really of secondary importance whether the expansion were effected in one or in two cylinders, yet this was a matter of considerable practical moment; and the general conclusion to be drawn from the present experience with the two classes of engines appeared to him to be that the compound engine enabled a higher pressure of steam to be employed than was practicable in a single cylinder, because in the latter the limit was sooner reached at which the extra friction of the engine absorbed the additional power obtained from the increased pressure. The further advantages to be derived from improvements in the construction of boilers and in the methods of firing should certainly not be undervalued; and although hand firing had in special trials been brought to such perfection as to give the remarkable evaporative results which had been mentioned, that plan would be wholly inapplicable to marine engines, where such large quantities of coal had to be dealt with under circumstances onerous to the stokers. It would however be a great step towards increasing the evaporative duty of the fuel when such improvements were made as should give the means of consuming more perfectly the products of combustion at present escaping unconsumed to the chimney; and this he hoped would be the great result that would be arrived at in the course of the next few years.

He proposed a vote of thanks to Mr. Bramwell for his very excellent and interesting paper, which was passed.

The Meeting was then adjourned to the following day.

In the afternoon the Members visited the Works of Messrs. Clay Inman and Co., Birkenhead Forge, where a number of forgings of the largest class were seen in process of production, including a marine half crank-shaft of 18 tons weight and 22 inches diameter in the bearings, the forging of which was witnessed. The heavy forgings are heated in Siemens' regenerative gas furnaces; and two of the largest steam hammers employed have a clear span of 20 feet between the standards, the hammer cylinder of 6 feet stroke being mounted in the centre of a straight wrought-iron girder. Hydraulic cranes are used for bringing the forgings from the heating furnaces, and handling them under the hammers. In one of the large lathes, 5 feet 6 inches high to the centre, for turning the largest marine crank-shafts, the face-plate is driven by a worm-wheel at the circumference, the worm being driven direct by a pair of 8 inch cylinder independent engines; and several separate small engines are employed for driving tools independently. For planing the circular roller-paths of large turntables for swing-bridges and gun-turrets an extemporised hydraulic planing machine is employed, having the cutting tool carried at the extremity of a strong radius bar, which is centred at the other end and worked by a hydraulic cylinder. The Members were entertained at luncheon at the Birkenhead Forge by Messrs. Clay Inman and Co.

The Birkenhead Dock Works, under the direction of Mr. G. F. Lyster, the Engineer to the Mersey Docks and Harbour Board, were then visited. The large graving dock is 750 feet long by 85 feet wide, and the adjacent dock 750 feet by 50 feet. The chain-cable and anchor testing works and the hydraulic machinery for working the dockgates and swing-bridges were seen, and the corn warehouses fitted with the hydraulic grain-traversing machinery described at a previous meeting of the Institution (see Proceedings Inst. M. E. 1869 page 208.) The Canada Works of Messrs. Thomas Brassey and Co., and the Britannia Engine Works of Messrs. James Taylor and Co., Birkenhead, were also visited.

Accumulator.

Fig 1 Elevation. Scale 1/24th

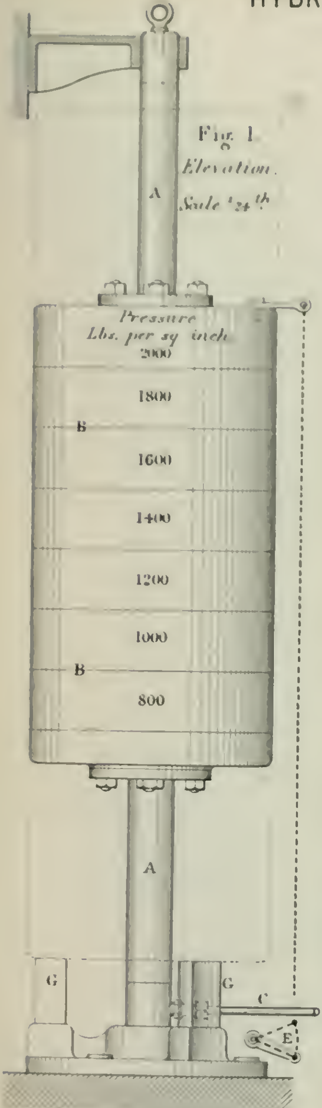


Fig. 2. Plan at bottom.

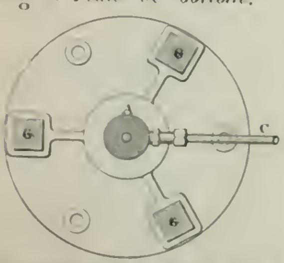
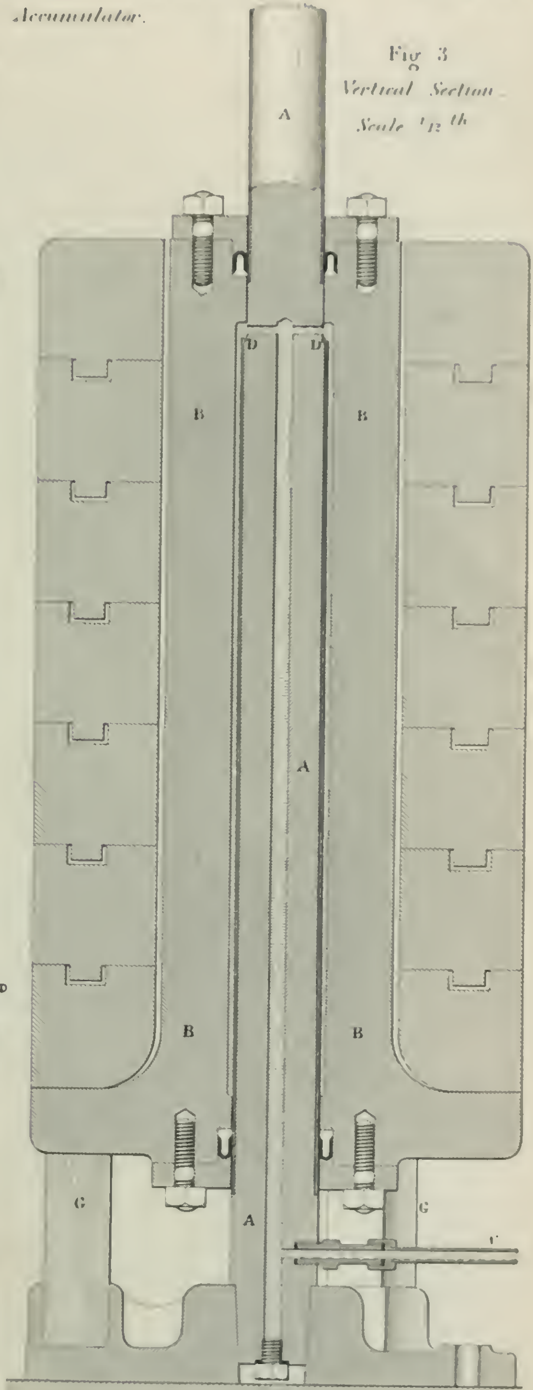


Fig 3 Vertical Section. Scale 1/12th



(Proceedings Inst M E. 1872)

Scale 1/12th 10 5 0 10 20 Inches.

Fixed Hydraulic Riveter.

Fig. 5. *Side Elevation.* Fig. 6. *End Elevation.*

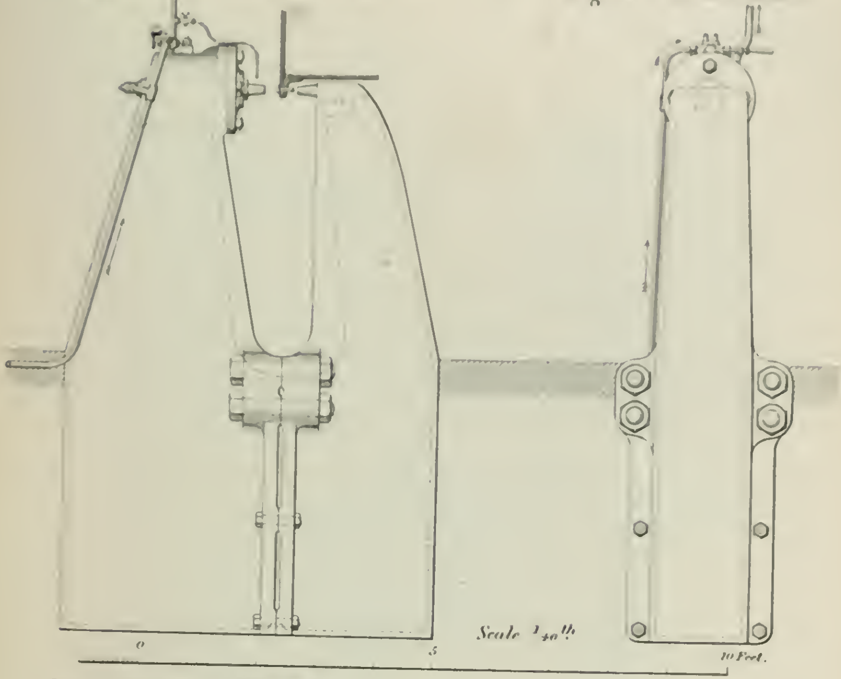


Fig. 7. *Plan.*

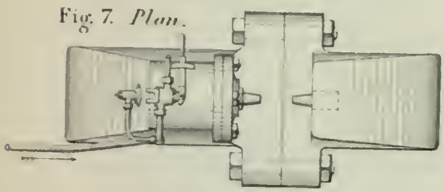
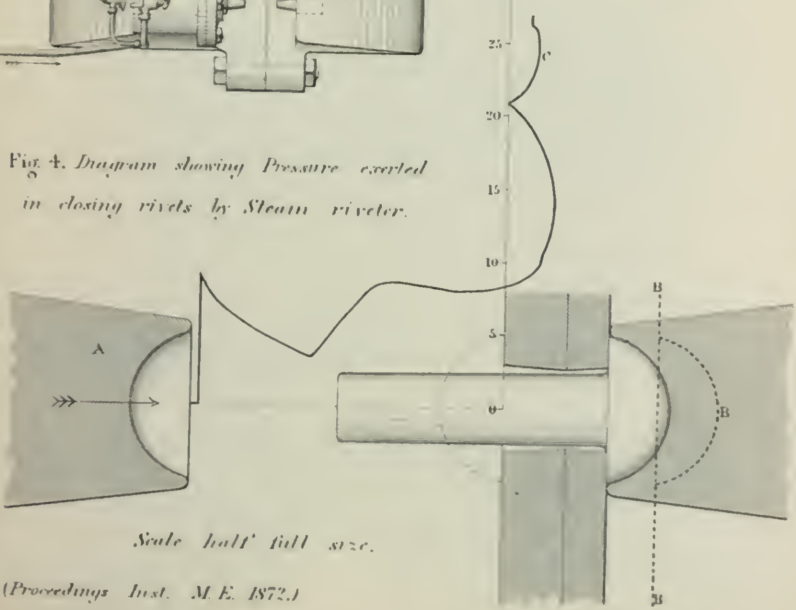


Fig. 4. *Diagram showing Pressure exerted in closing rivets by Steam riveter.*



Scale half full size.

(Proceedings Inst. M.E. 1872.)

Fixed Hydraulic Riveter.

Fig 8. Longitudinal Section
Scale 1/20th

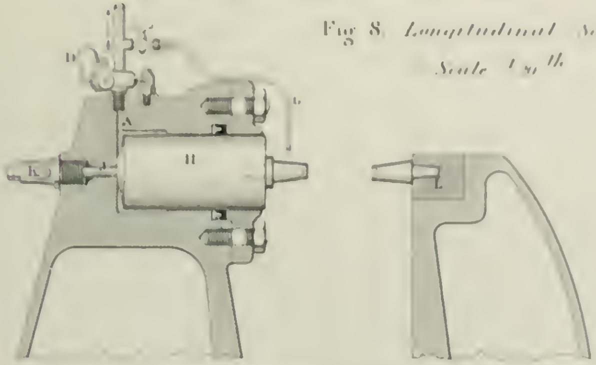


Fig 9. Back Elevation

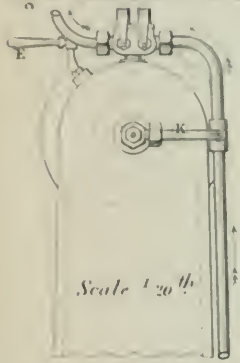


Fig 11. Sectional Plan of Valve Box.
Scale 1/5th

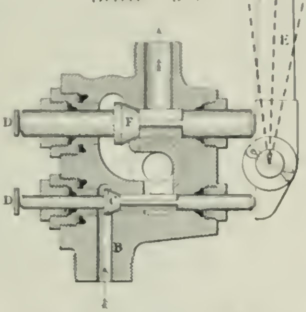


Fig 10. Front Elevation

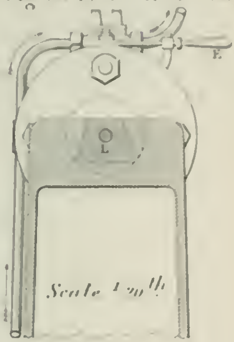
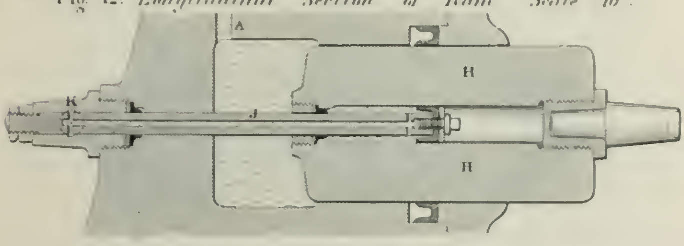
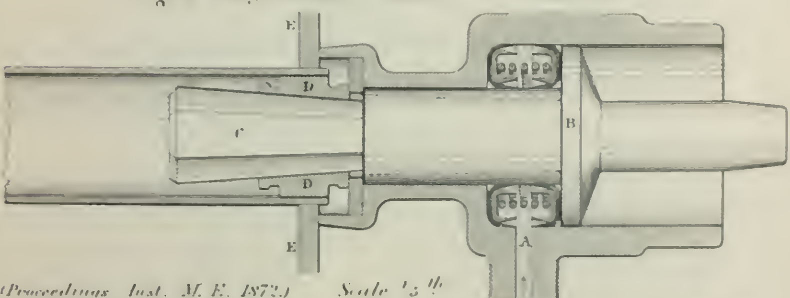


Fig 12. Longitudinal Section of Ram Scale 1/10th



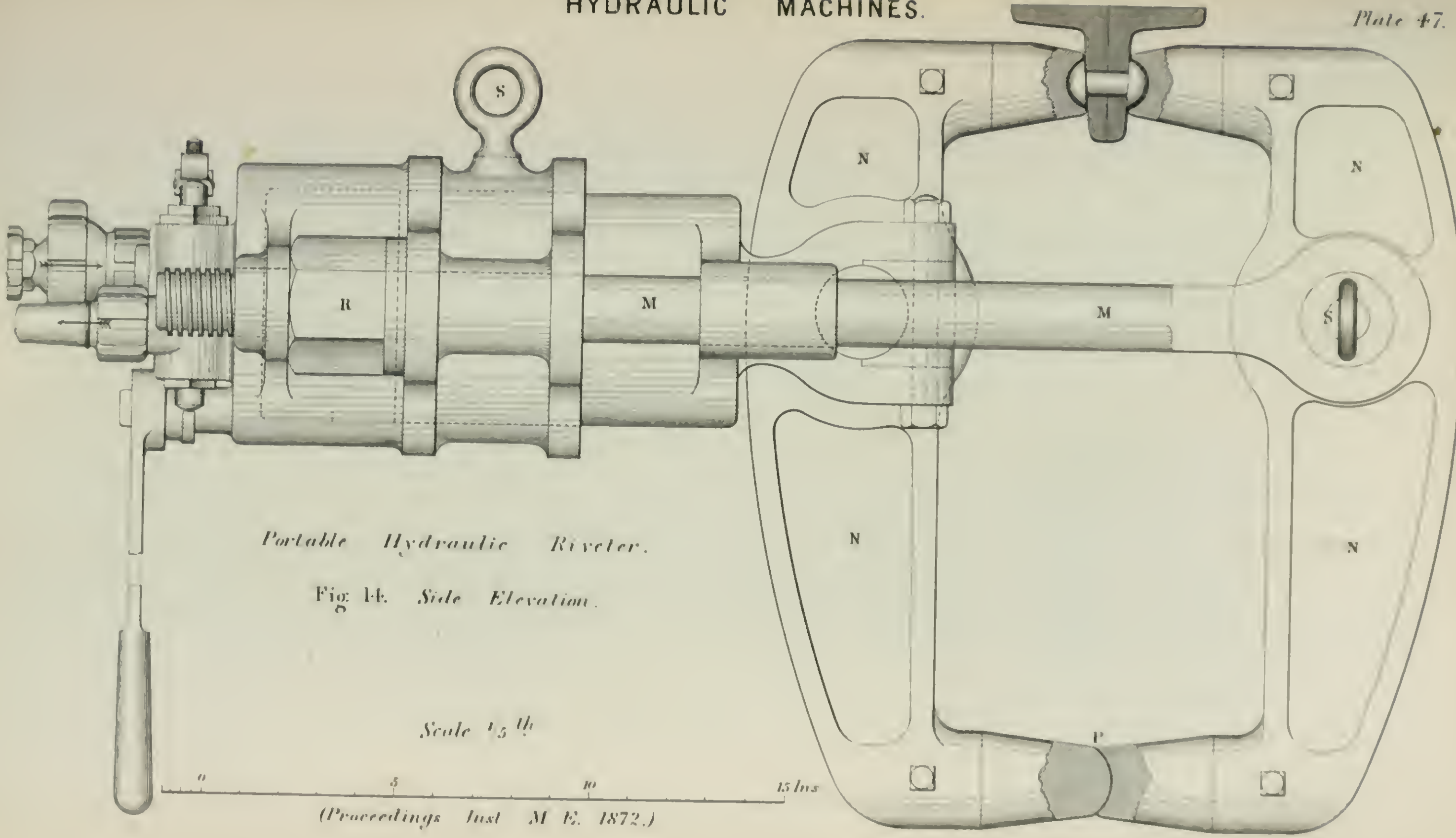
Hydraulic Tube Expander.

Fig 13. Longitudinal Section. Scale 1/5th



(Proceedings Inst. M. E. 1872.) Scale 1/5th

0 5 10 15 Inches



Portable Hydraulic Riveter.

Fig. 14. *Side Elevation.*

Scale 1/5 th

(Proceedings Inst M E. 1872.)

HYDRAULIC MACHINES.

Portable Hydraulic Riveter.

Fig. 15. *Side Elevation.*

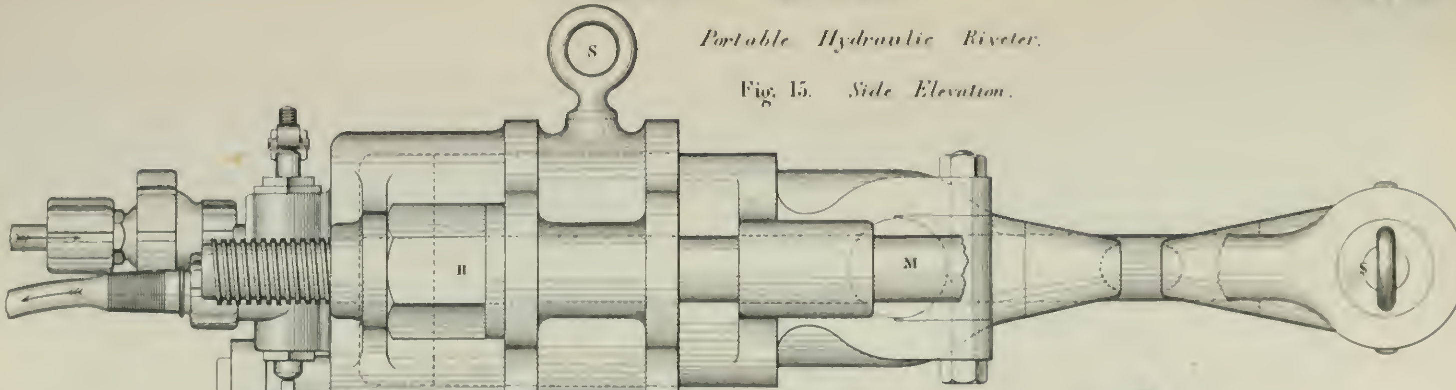
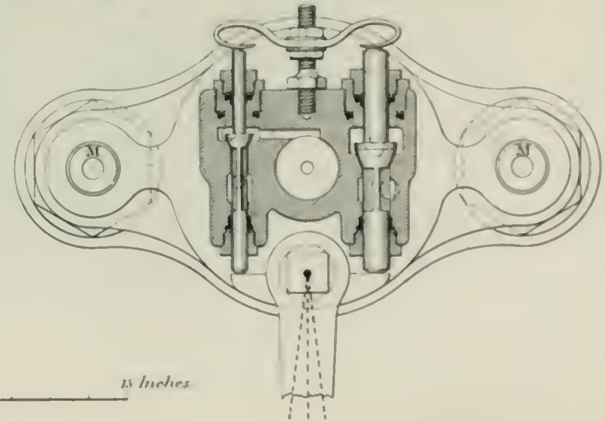


Fig. 16.

Transverse Section through Valvebox.



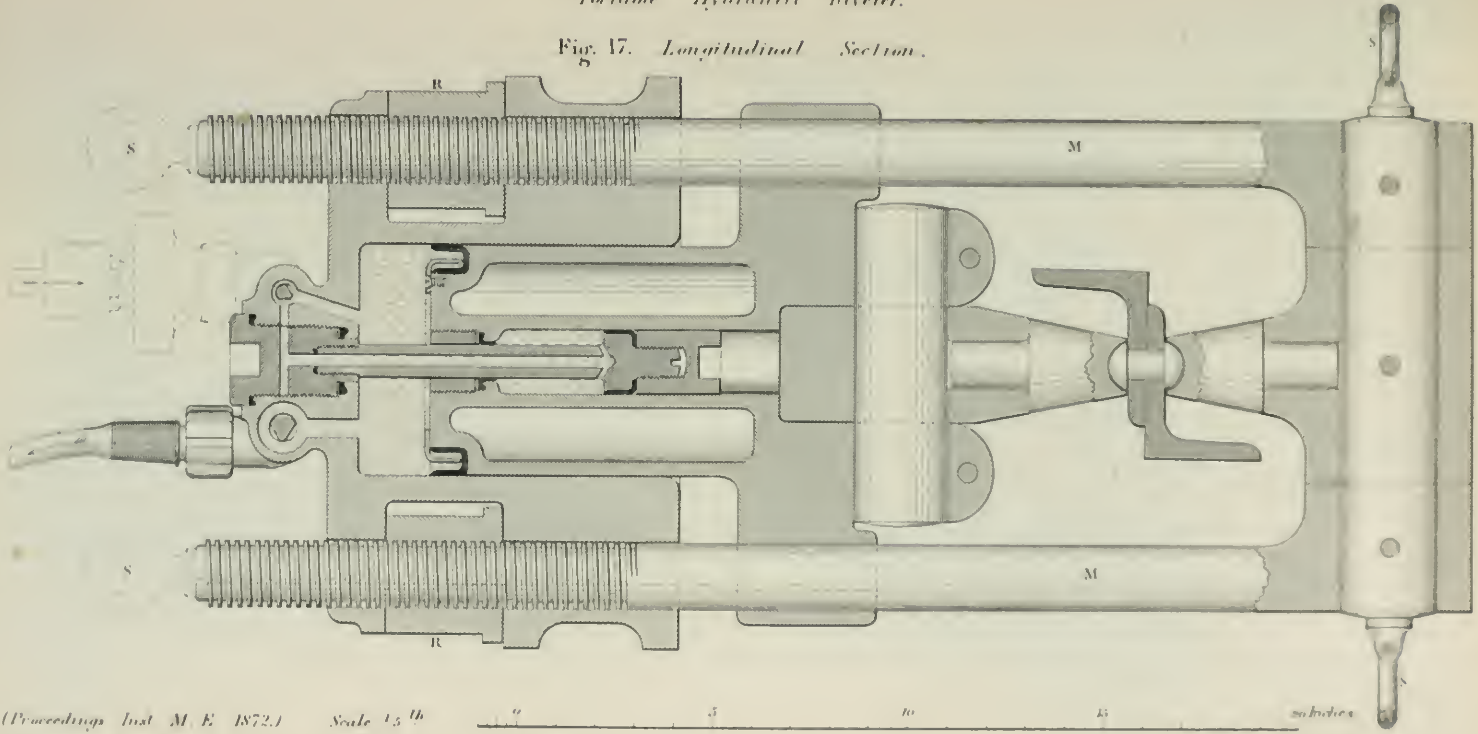
Scale 1/5 th

0 5 10 15 *Inches*

(Proceedings Inst M E 1872)

Portable Hydraulic Riveter.

Fig. 17. *Longitudinal Section.*



(Proceedings Inst. M. E. 1872.) *Scale 1/5th*

0 5 10 15 20 Inches

Plate 30.

HYDRAULIC MACHINES

Universal Joints for Moveable Hydraulic Machines

Fig 18 Full-size Section of Packing Leather for Accumulator and Hydraulic Machines.

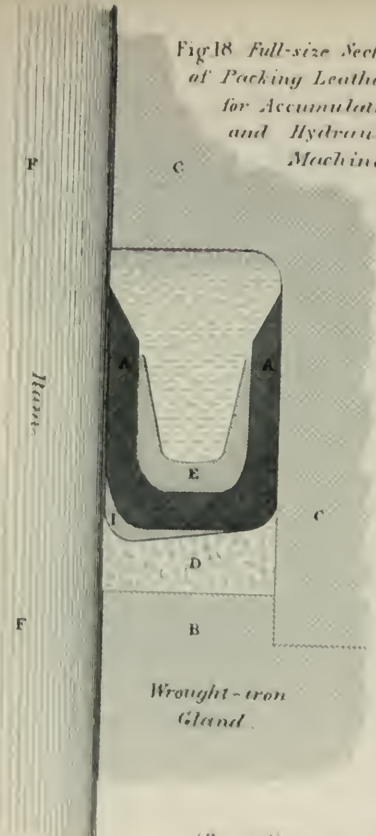
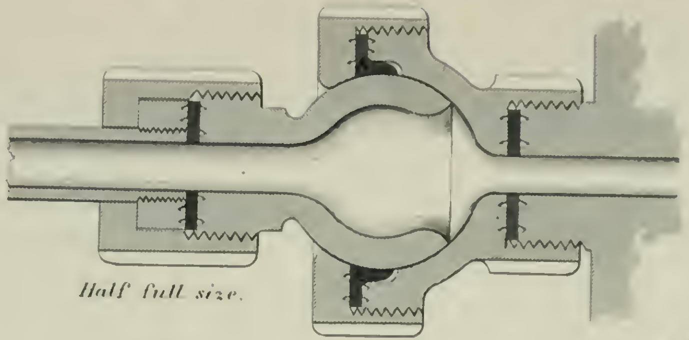


Fig. 19. Ball and Socket Joint



Half full size.

Fig. 20.

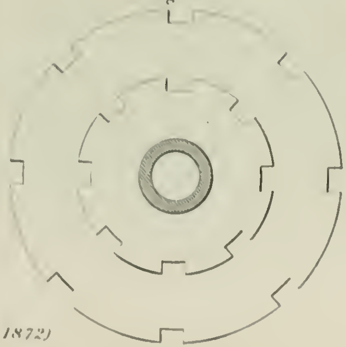
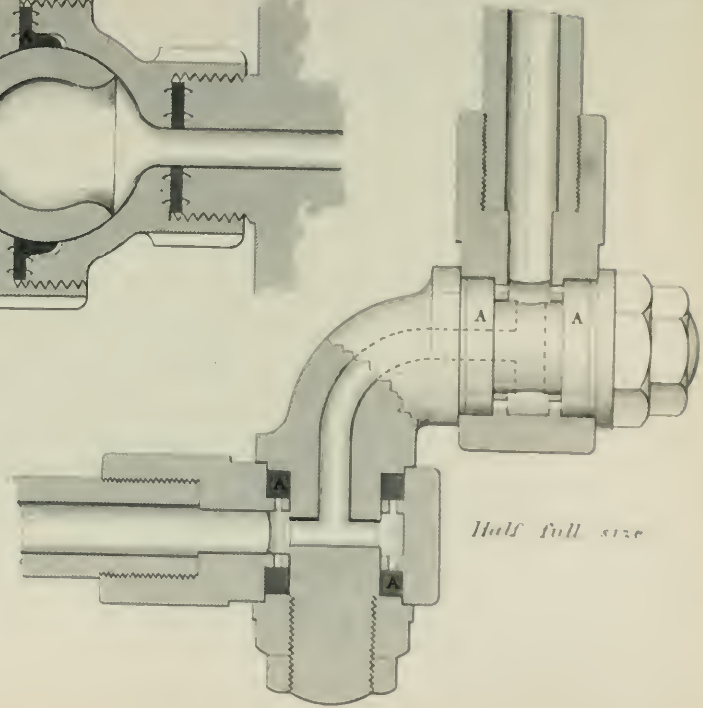


Fig 21

Double Right-angled Joint



Half full size

(Proceedings Inst M E 1872)

HYDRAULIC MACHINES.

Plate 51.

Various Applications of Portable Hydraulic Riveter.

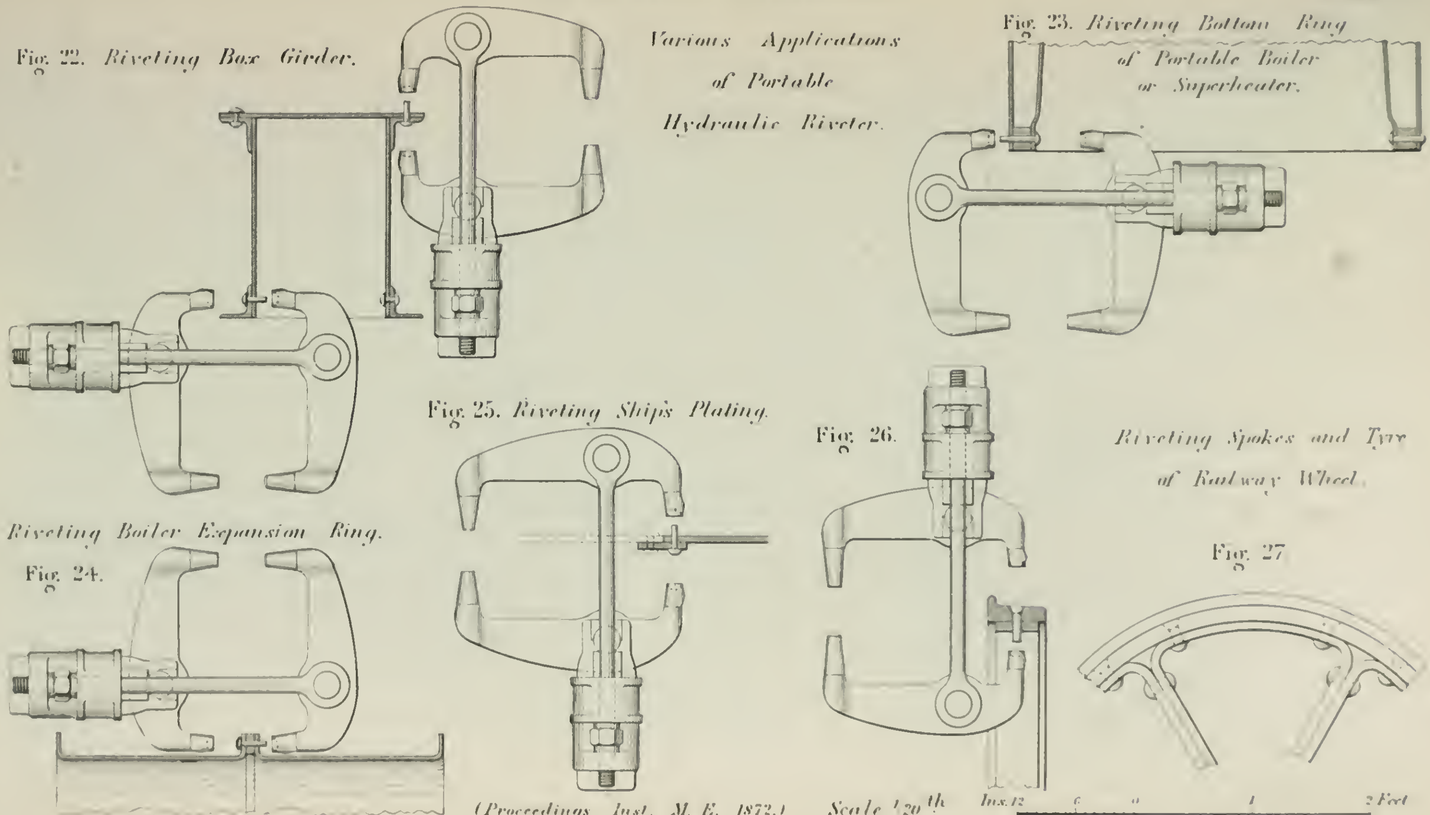


Fig. 22. *Riveting Box Girder.*

Fig. 23. *Riveting Bottom Ring of Portable Boiler or Superheater.*

Fig. 24. *Riveting Boiler Expansion Ring.*

Fig. 25. *Riveting Ships Plating.*

Fig. 26.

Fig. 27. *Riveting Spokes and Tyre of Railway Wheel.*

(Proceedings Inst. M. E. 1872.) *Scale 1/20th*

Moveable Hydraulic Riveter applied to rivet large marine Boilers

Fig. 28

Transverse Section

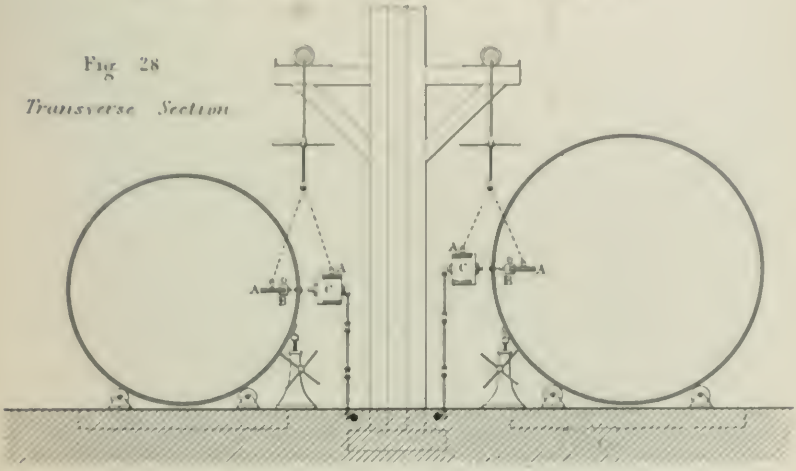


Fig. 29. *Plan.*

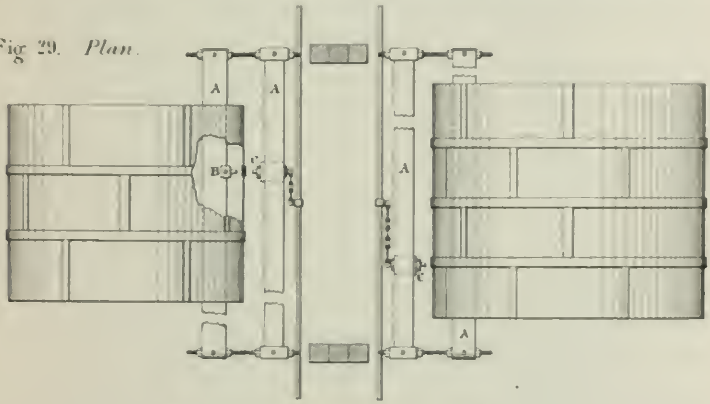
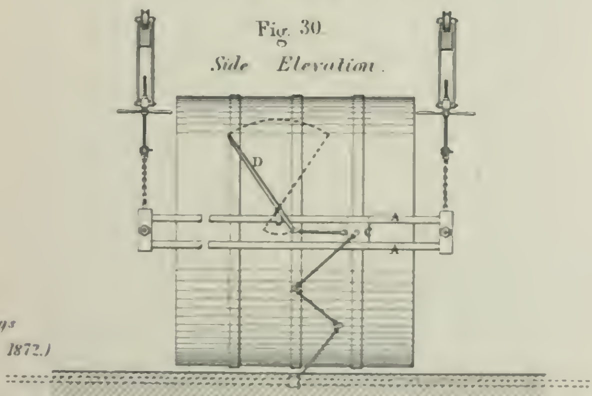


Fig. 30.

Side Elevation.



(Proceedings Inst. M.E. 1872.)

Scale $^1/_{120}$*th*

HYDRAULIC MACHINES.

Application of Portable Hydraulic Riveter to Iron Shipbuilding

Fig. 31. *Transverse Section of Ship.*

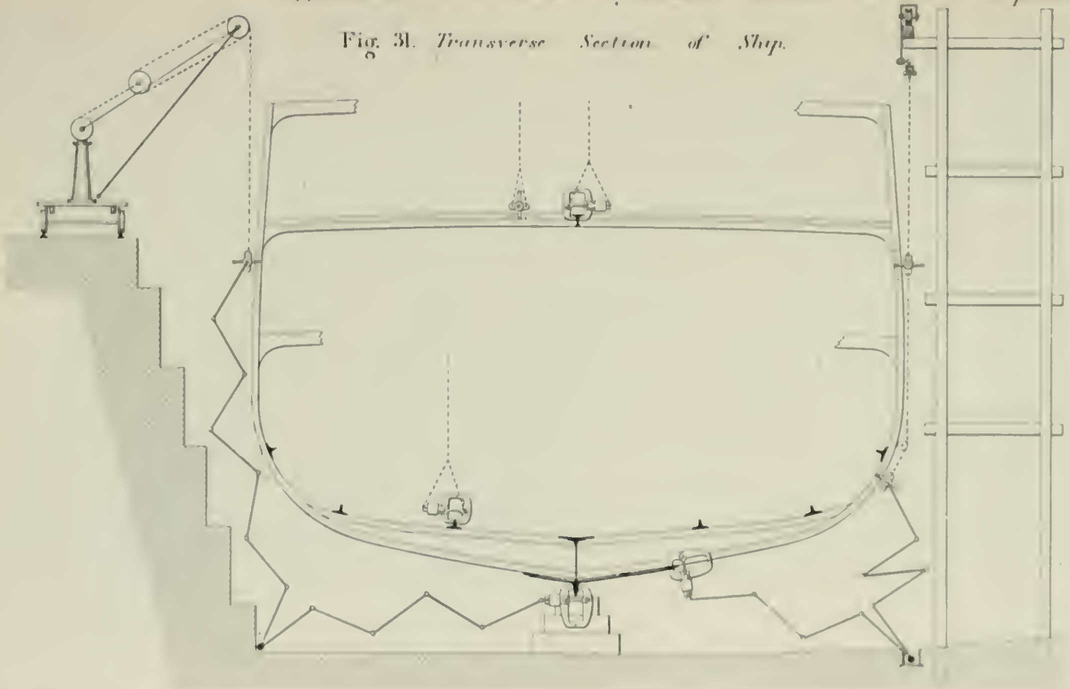
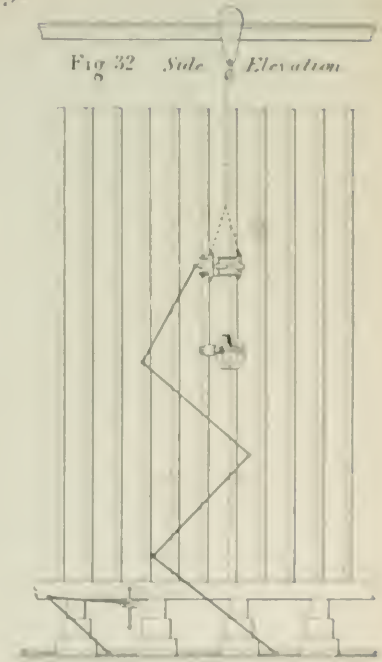
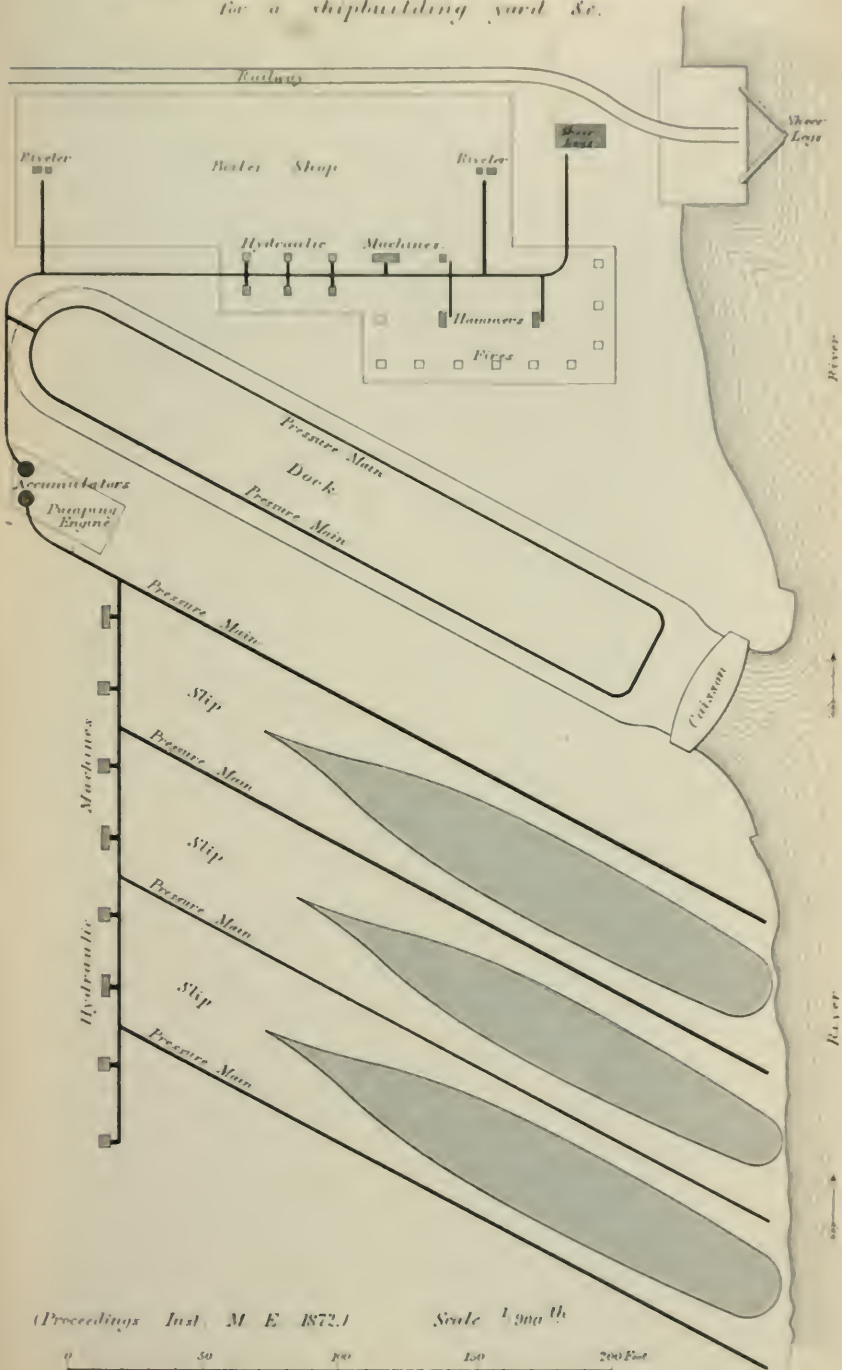


Fig. 32 *Side Elevation*



Scale 1/50 th 10 5 0 10 20 30 Feet

Fig. 33. *General Plan*
showing arrangement of Hydraulic Machinery
for a shipbuilding yard &c.

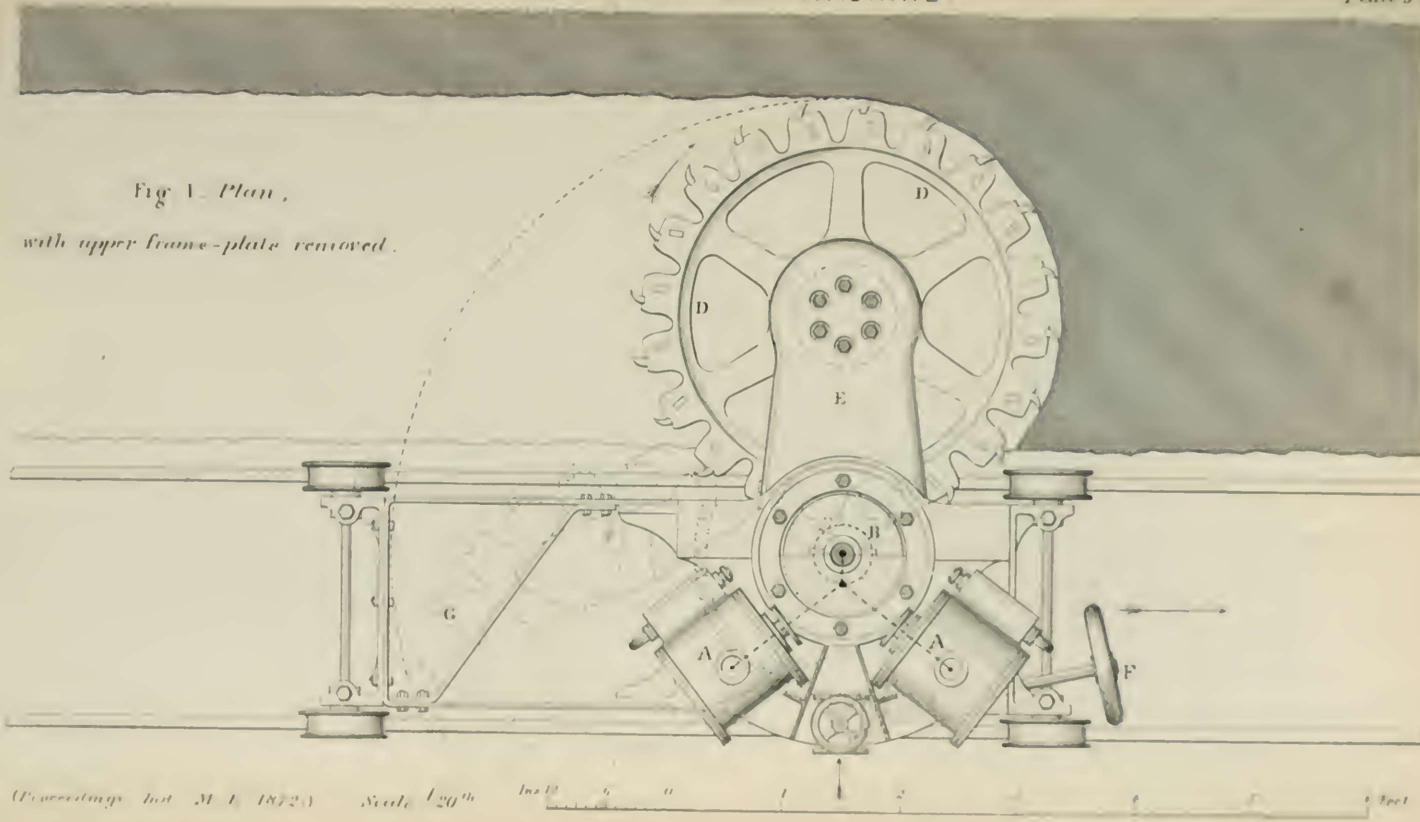


(*Proceedings Inst. M. E. 1872.*) *Scale* $^{1}/_{900}{}^{th}$

COAL CUTTING MACHINE

Fig 1. *Plan,*

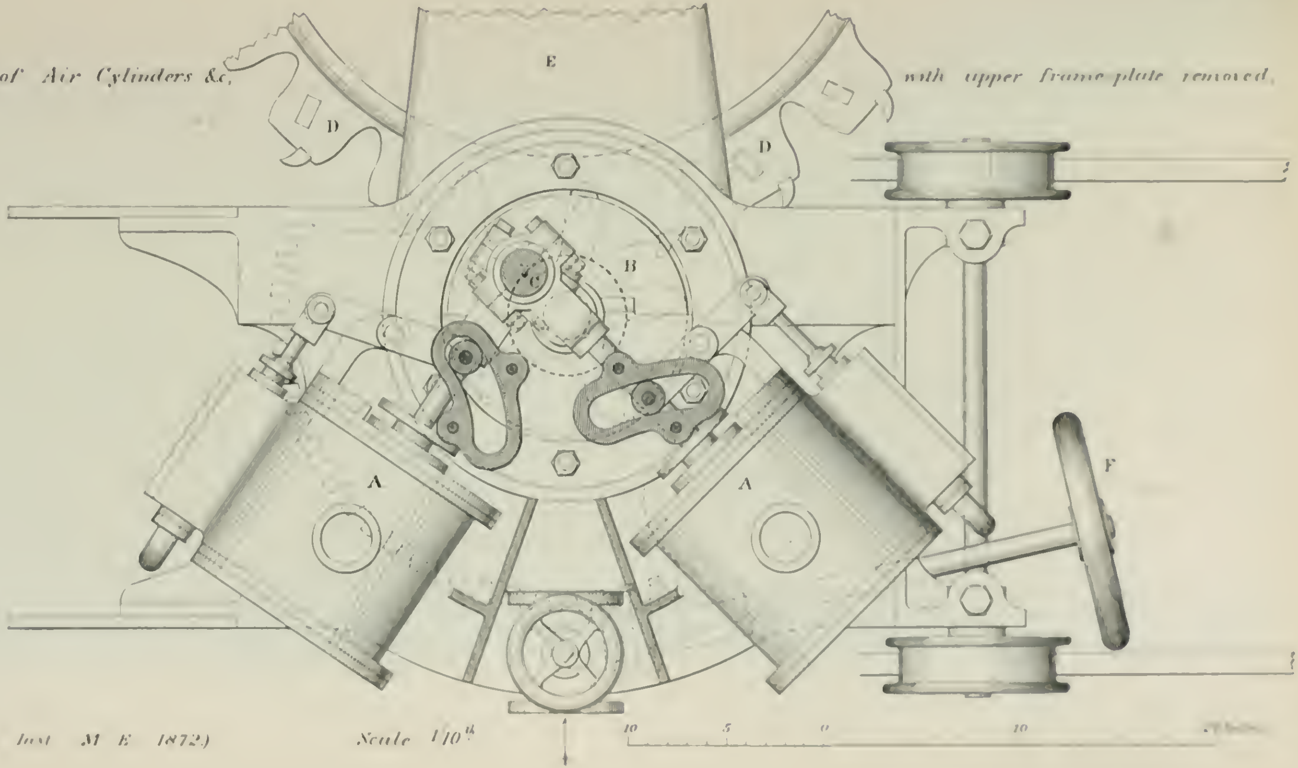
with upper frame-plate removed.



(Proceedings Inst. M. E. 1872.) *Scale* $^1/_{20}$th

COAL CUTTING MACHINE

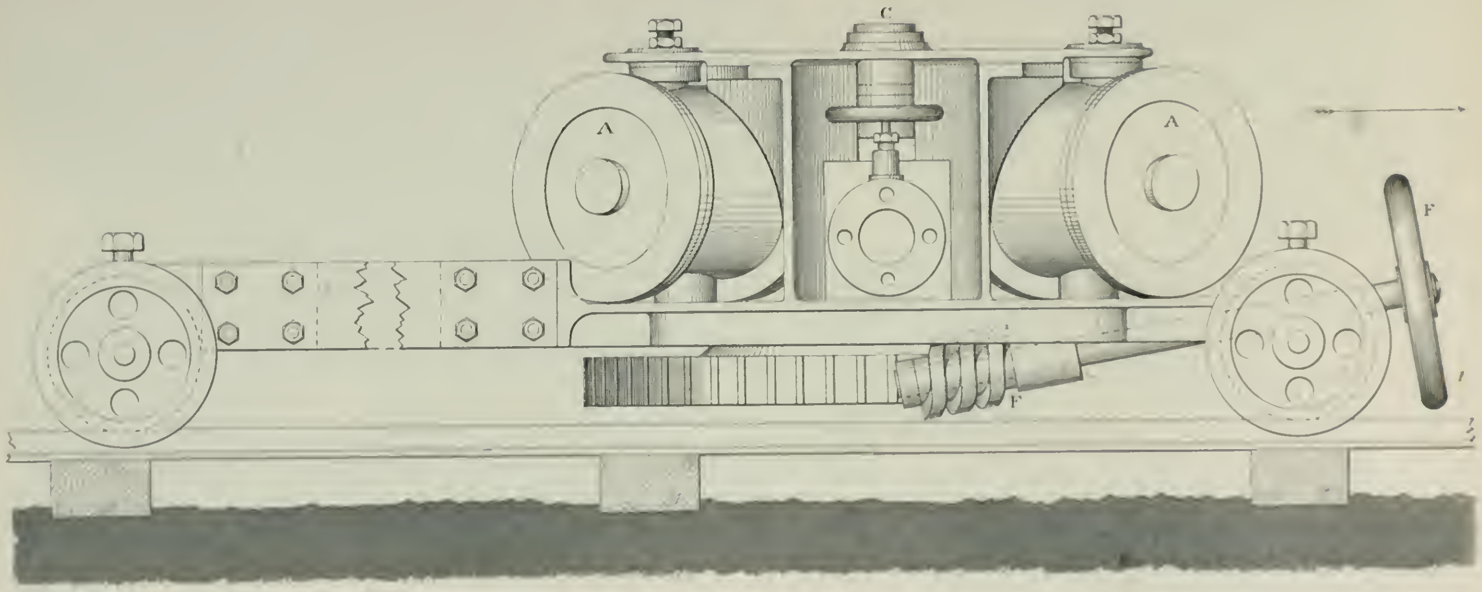
Fig 2. *Plan of Air Cylinders &c, with upper frame plate removed.*



(Proceedings Inst M E 1872) *Scale 1/10th*

COAL CUTTING MACHINE

Fig. 3. *Side Elevation*

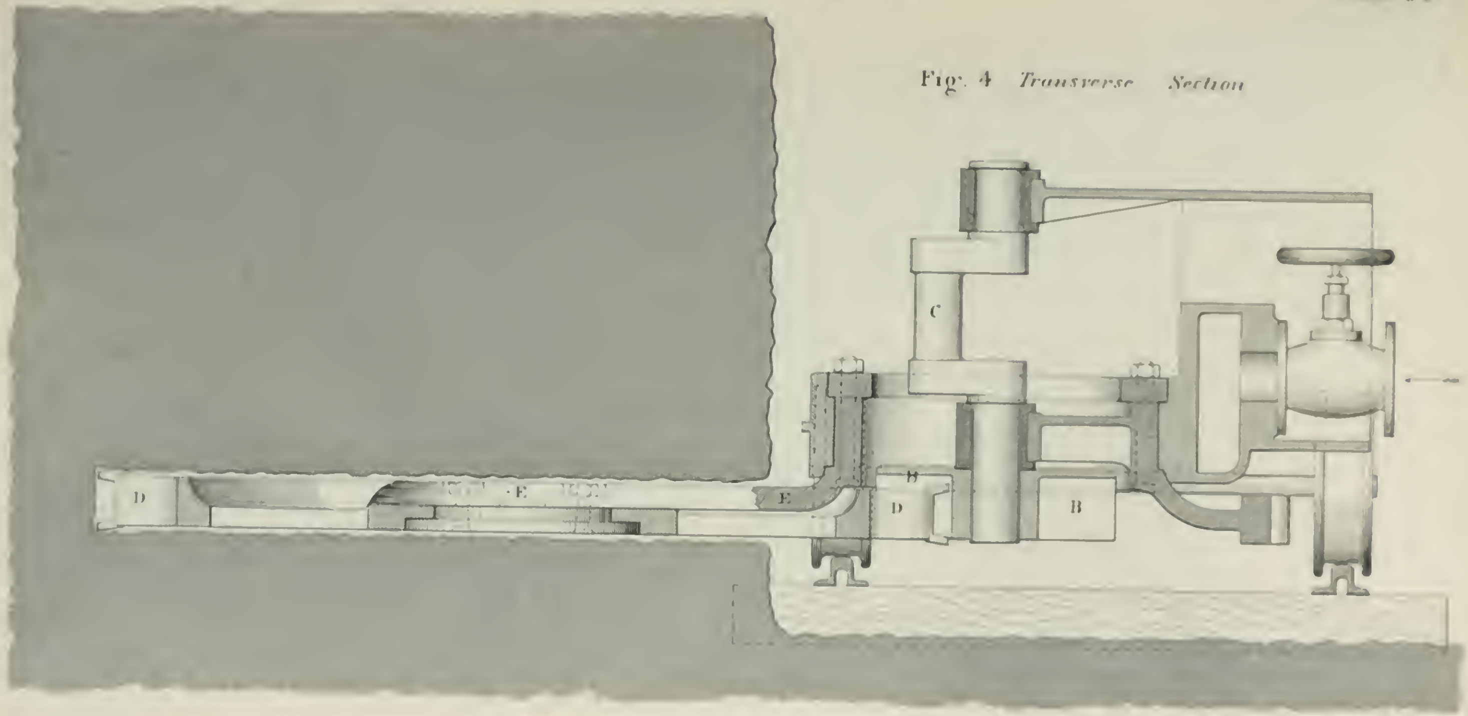


(*Proceedings Inst. M. E. 1872.*) *Scale 1/10th.* 10 5 0 10 20 30 Inches

COAL CUTTING MACHINE.

Plate 58

Fig. 4 *Transverse Section*



(Proceedings Inst. M. E. 1872.)

Scale 1/10th

COAL CUTTING MACHINE.

Plate 59.

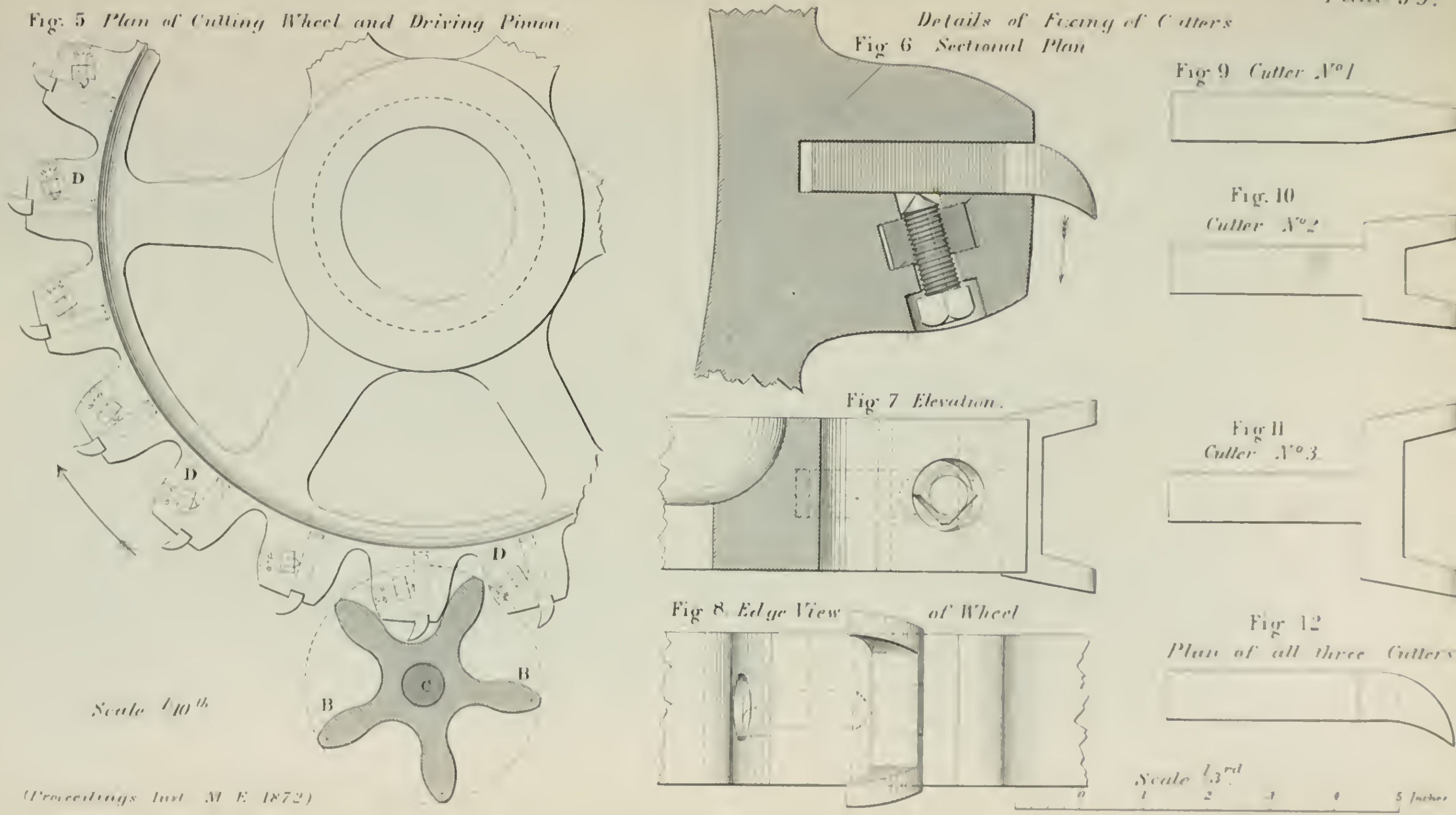


Fig: 5 Plan of Cutting Wheel and Driving Pinion

Scale 1/10th

Details of Fixing of Cutters

Fig 6 Sectional Plan

Fig 7 Elevation.

Fig 8 Edge View of Wheel

Fig 9 Cutter No 1

Fig. 10 Cutter No 2

Fig 11 Cutter No 3

Fig 12 Plan of all three Cutters

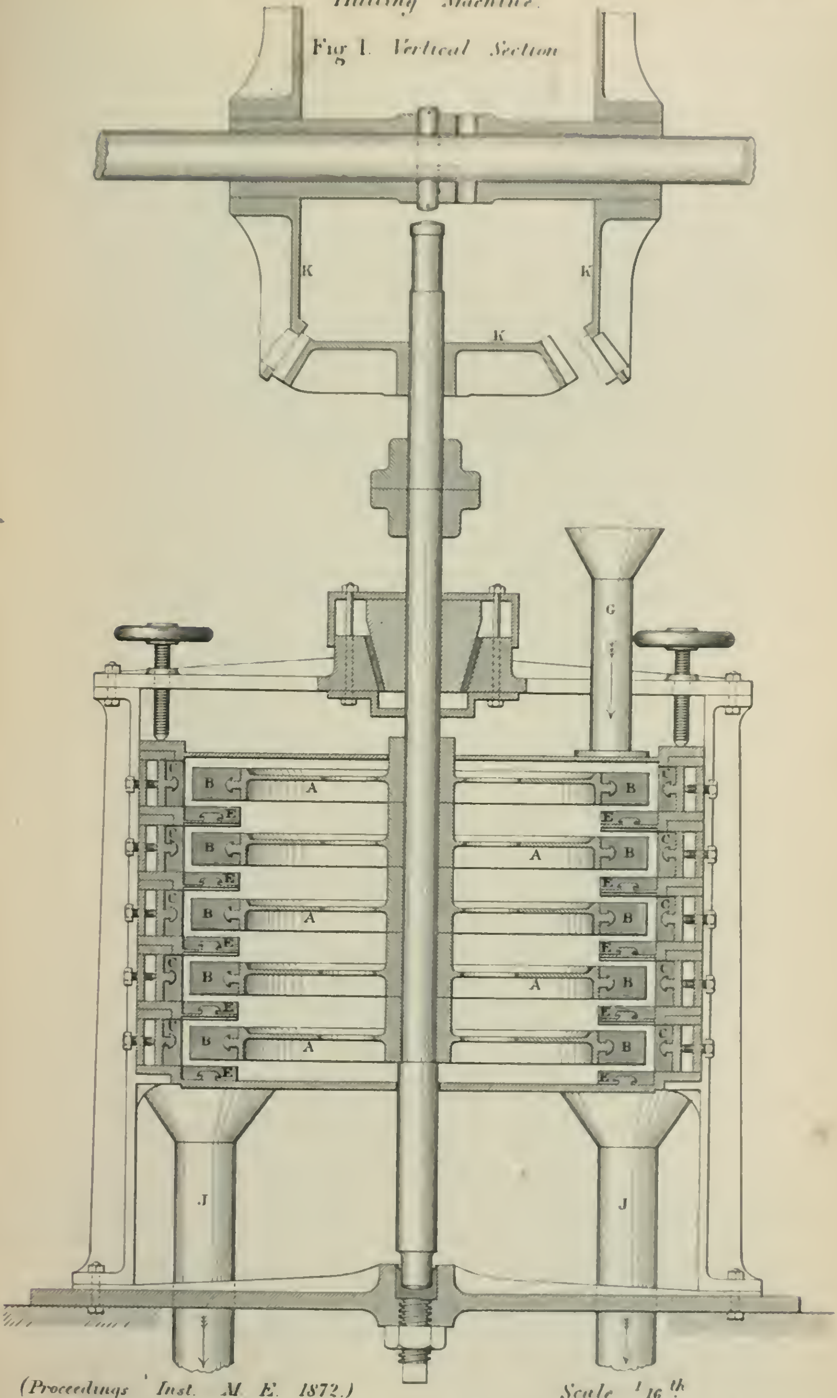
Scale 1/3rd

(Proceedings Inst M E 1872)

BUCHHOLZ CORN MILL. *Plate 60*

Hulling Machine.

Fig 1. *Vertical Section*



(Proceedings Inst. M. E. 1872.)

Scale $^1/_{16}$th

10 5 0 10 20 30 40 Inches.

BUCHHOLZ CORN MILL

Plate 61.

Hulling Machine.

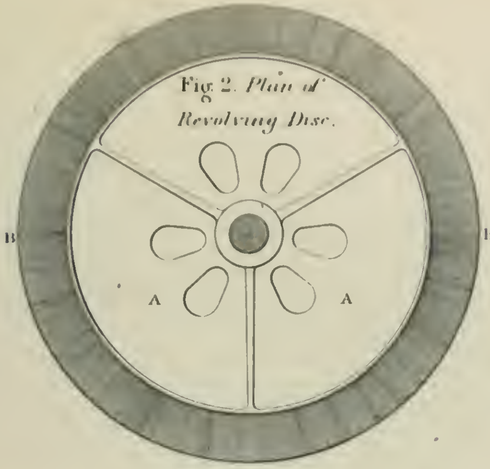


Fig. 2. *Plan of Revolving Disc.*

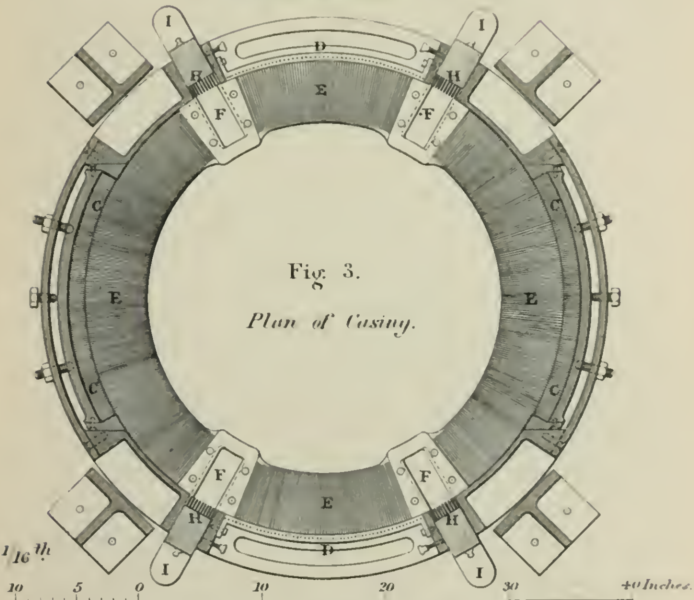
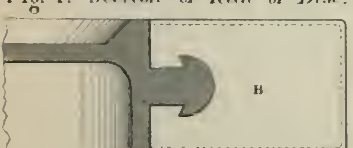


Fig. 3. *Plan of Casing.*

Scale 1/16th.

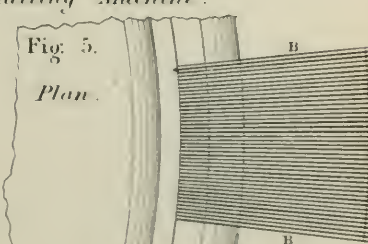
Detail of Blades of Hulling Machine.

Fig. 4. *Section of Rim of Disc.*



Scale 1/4th.

Fig. 5. *Plan.*



(Proceedings Inst. M. E. 1872.)

BUCHHOLZ CORN MILL.

Plate 62

Semolina Mill

Fig 6 Side Elevation.

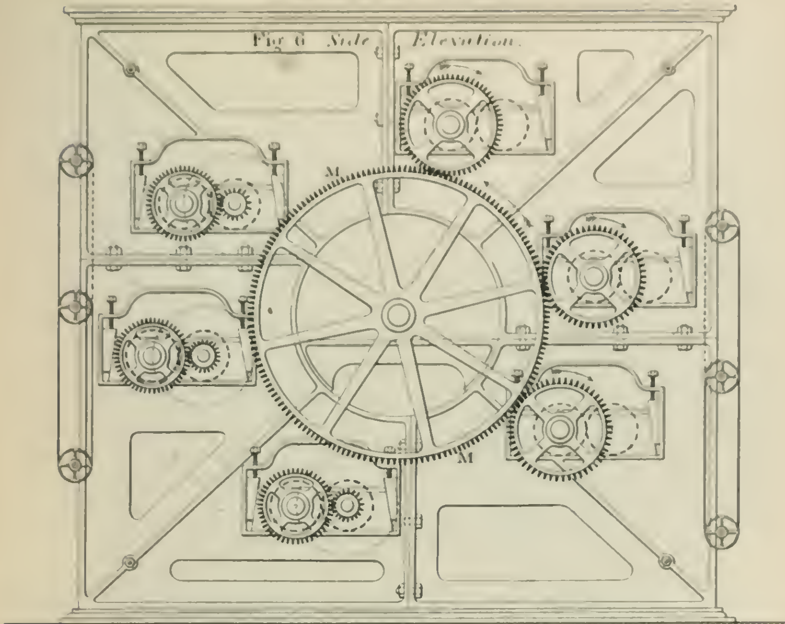
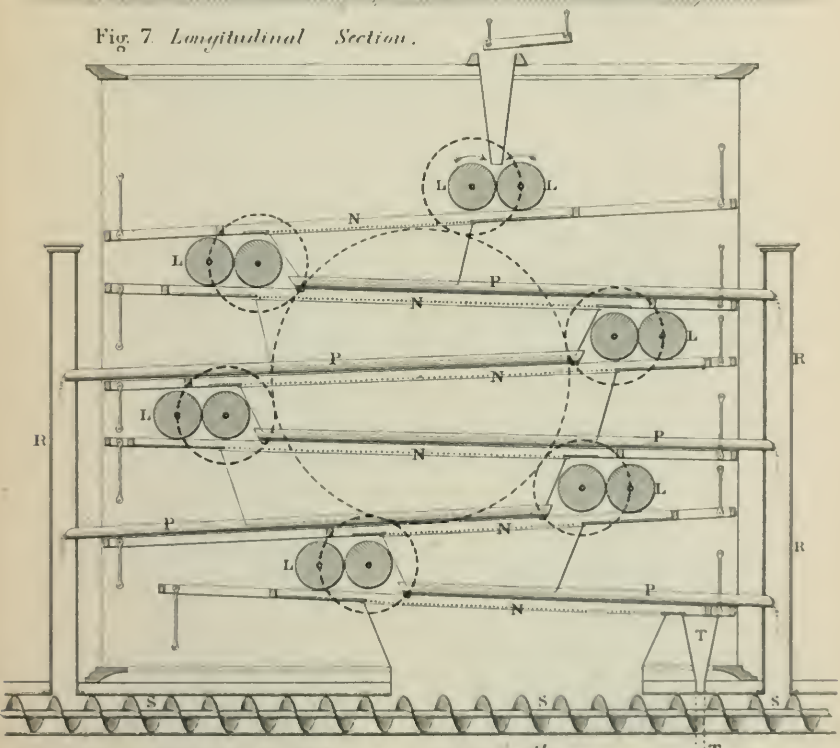


Fig. 7 Longitudinal Section.



(Proceedings Inst. M. E. 1872.) *Scale $^1/_{40}$th*

0 1 2 3 4 5 6 7 8 9 10 Feet

BUCHHOLZ CORN MILL.

Semolina Mill

Fig. 8. *End Elevation*

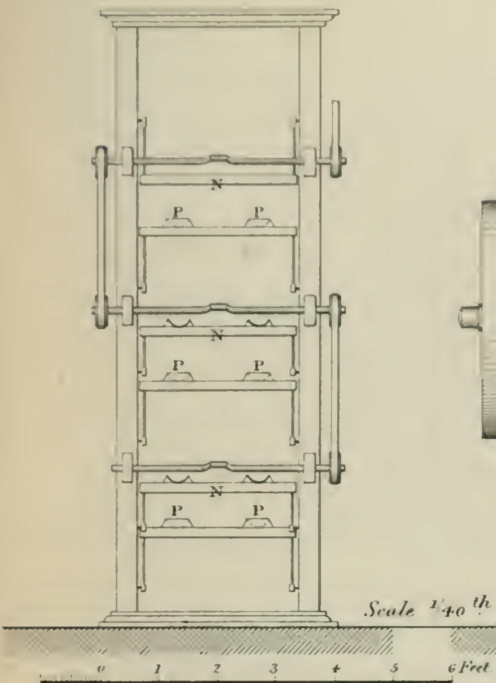
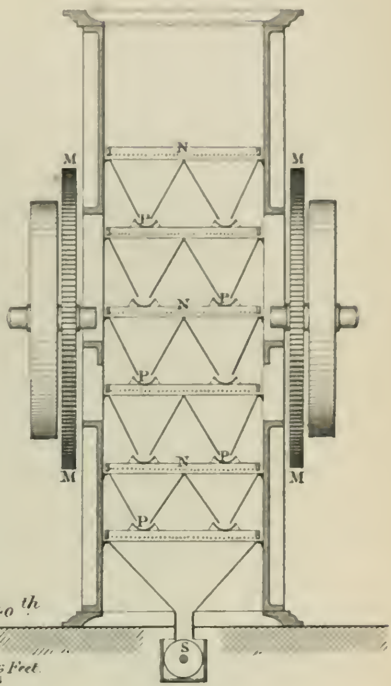


Fig. 9. *Transverse Section.*



Scale 1/40th

Grooving of Rollers.

First Pair of Rollers.

Fig. 10. *Plan of Surface.*

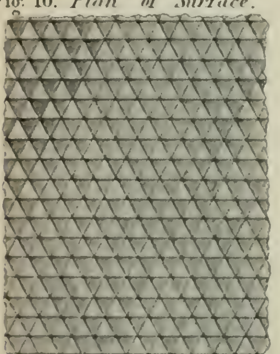
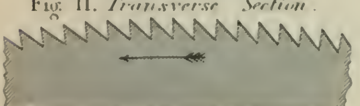


Fig. 11. *Transverse Section.*



Succeeding Pairs of Rollers.

Fig. 12. *Plan of Surface.*

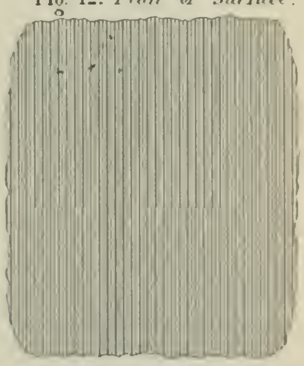
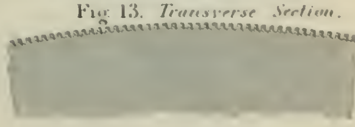


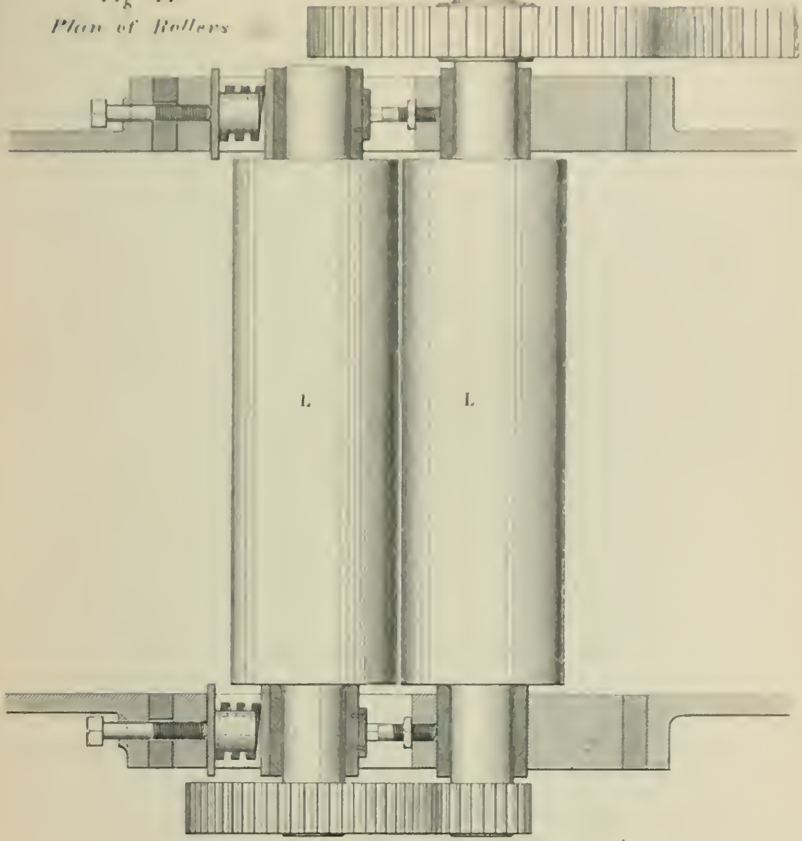
Fig. 13. *Transverse Section.*



Full size.

Semolina Mill

Fig 14
Plan of Rollers



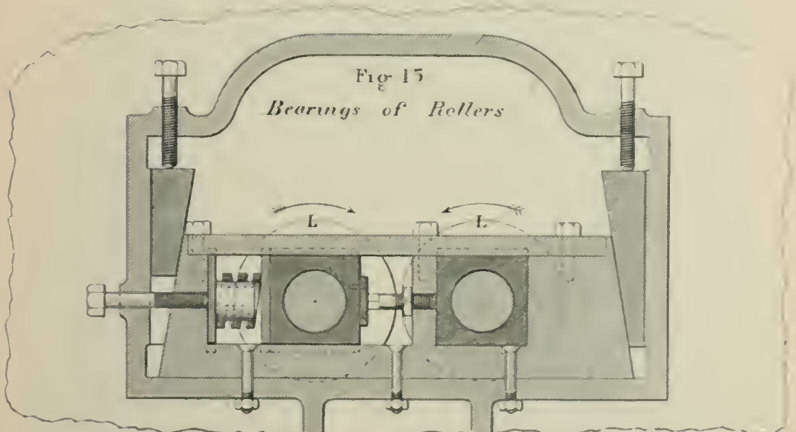


Fig 15
Bearings of Rollers

(Proceedings Inst. M. E. 1872)

Scale $^1/_{12}$th

10 5 0 10 20 30 Inches

BUCHHOLZ CORN MILL

Plate 65.

Centrifugal Separator

Scale $1/24^{th}$

Ins 12 6 0 1 2 Feet

Fig. 16 *Vertical Section.*

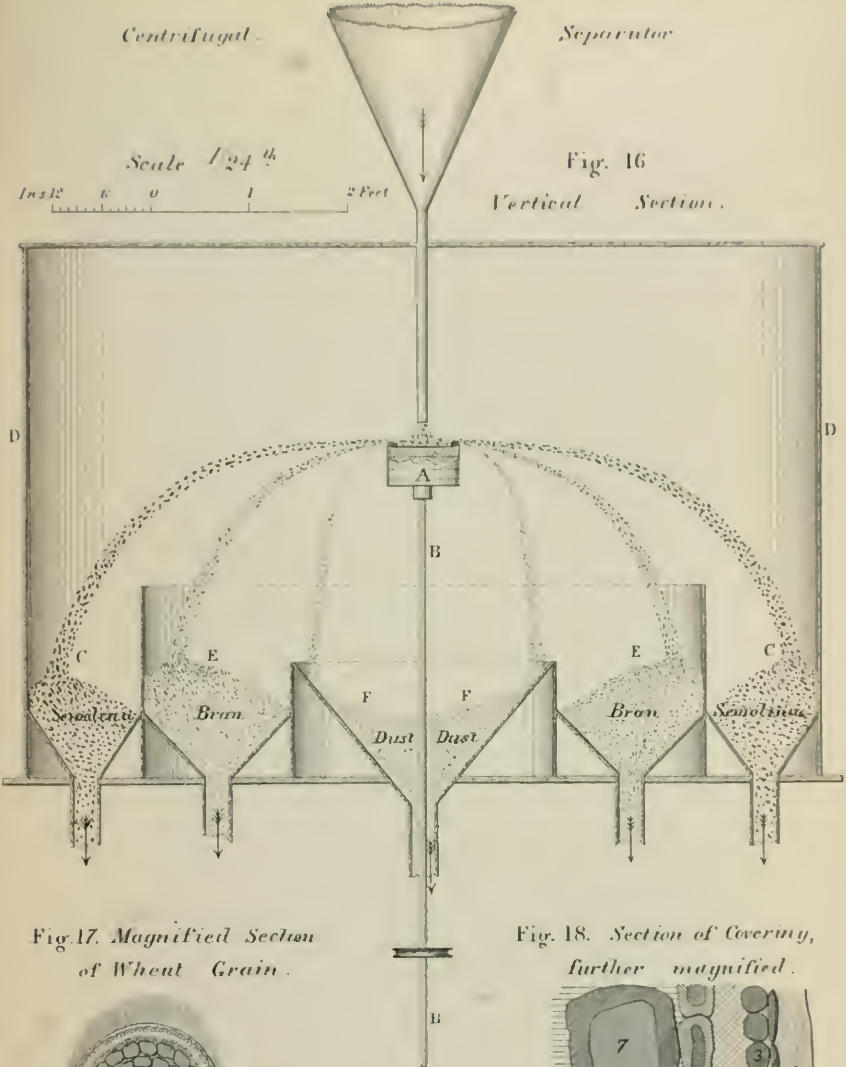
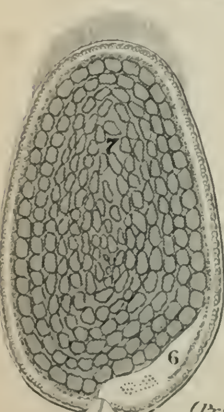


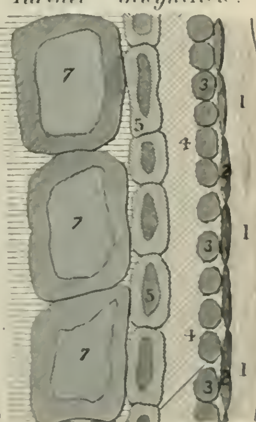
Fig. 17. *Magnified Section of Wheat Grain.*



1 *Epidermis.*
2 *Epicarpis.*
3 *Endocarpis.*
4 *Testa membrane.*
5 *Embryo membrane.*
6 *Embryo.*
7 *Perispermum:– Flour Cells.*

(1–5) *Bran.*

Fig. 18. *Section of Covering, further magnified.*



(Proceedings Inst. M. E. 1872)

The Adjourned Meeting of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Wednesday, 31st July, 1872; C. William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The following paper was read:—

ON THE APPLICATION OF WATER PRESSURE TO SHOP TOOLS AND MECHANICAL ENGINEERING WORK.

By Mr. RALPH HART TWEDDELL, of London

Hydraulic Power having been successfully used for so great a variety of purposes since its original application in the hydraulic press, it appears singular that its employment as the power for working machine tools has hitherto been so limited. Perhaps the chief explanation of this circumstance is to be found in the fact that, in order to obtain the full benefit which would be derived from the adoption of this means of distributing power, the arrangement of works and tools would have to be specially modified. A considerable portion of the works would have to be expressly arranged to suit the new driving power; and in works already constructed a large quantity of existing shafting, gearing, and belting would thus be rendered useless. To a certain extent hydraulic power is best suited for heavy work, and for driving machines that have a rectilinear or a reciprocating motion, and would consequently not be suitable for such cases as shops in which a number of small lathes &c. are employed; but this objection does not apply to the construction of iron ships, bridges, boilers, and similar descriptions of work.

The most important feature in the application of hydraulic power to such purposes is its advantage as a means of distributing the power supplied by the engine or other prime mover. There are three principal modes of distributing power :—by shafting, belts, and gearing ;—by compressed air ;—and by water pressure. The steam engine is generally the source of power common to all three modes.

The first mode of transmitting power—namely by shafting—is the most limited as regards the extent of area over which it can be applied; but it is convenient for application to most of the machine

tools now in general use. Shafting is however very expensive, requiring many standards and supports, and involving great weight of pulleys, geared wheels, and plummer blocks; it requires great care in erection, and constant attention while running; it is wasteful of power in friction, and wear and tear of leather belts, and is a frequent source of danger. Another serious objection is that it involves a constant demand on the engine for a large amount of power, whether the machinery in connection with it is running or not.

The second means of distributing power—by compressed air—has hitherto been the least efficient of the three modes, and is unsuitable for the class of work now under consideration. It is not an economical mode, owing to the loss of power consequent upon the liberation of the heat developed in compressing the air, the heat so liberated being lost before the point of application is reached; the difficulty of detecting leakage is also an objection. The fact however of air cooling in expanding renders this mode of transmitting power valuable in mines, tunnels, and confined places, such as stoke-holes of steamers; in all such cases many laborious operations might probably be performed with advantage by the use of compressed air.

The third mode of distributing power is by means of water conveyed through pipes, under pressure from a natural or artificial head, to the various machines to be worked by it. The pressure used by the writer varies from 1000 lbs. to 1750 lbs. per square inch; and as it is not generally possible or convenient to obtain even the lowest of these pressures from any natural head of water, it is obtained from an artificial head produced by means of a direct load or weight, against which the water to be used is pumped, the load thus producing the pressure that would be due to the elevation of a head of water. The "accumulator" by which this is effected consists of a loaded plunger or ram working in a cylinder, the water being pumped into the cylinder under the pressure of the load upon the ram.

It is chiefly for intermittent requirements, as in the case of shop tools, especially those of the heaviest class, that the accumulator

is of advantage; and little or nothing is gained by its intervention for doing any work of a continuous description, because in that case the engine would still be required to be of the same power as is now needed for performing the greatest amount of work that may be wanted at one moment. The principal ground upon which the use of water pressure supplied by an accumulator appears to be preferable as a means of distributing power is that the accumulator ceases to draw upon the engine when there is no useful work to be done, and thus saves fuel and power, together with the wear and tear that take place when an engine is always driving the gearing and shafting, although the machinery driven may not be at work.

The form of accumulator shown in Figs. 1 to 3, Plate 44, is on the differential principle, which ensures a stiffness of spindle not otherwise to be obtained, and gives a compact arrangement for cases where so small a quantity of water is required as for supplying say only a single riveting machine. The ram or spindle A of the accumulator is here fixed, and acts as a guide, while the cylinder B slides upon it and is loaded with the weight necessary for giving the required pressure to the water. This plan of accumulator, although not new, possesses several good features. The water is pumped in at the bottom at C, and fills up the annular space surrounding the spindle; and the whole weight has to be lifted by the water acting only on the shoulder D of the spindle, which is made by a brass bush $\frac{1}{2}$ inch thick all round the spindle. A compact arrangement is thus obtained, and any required cubic capacity is got by lengthening the stroke. The accumulator is supplied by two pumps, each $1\frac{3}{8}$ inch diameter and $3\frac{1}{2}$ inches stroke, running at about 100 to 120 revolutions per minute. When the loaded cylinder B reaches the top of its stroke, it is made to close the suction cock E of the pumps, thus stopping the supply of water. When it is desired to put in a new packing leather at the bottom, the weighted cylinder is let down to rest upon blocks placed on the wood chocks G at bottom, and the spindle is drawn up out of its tapered seat by the eye-bolt

at top; for renewing the top leather, the bracket holding the top end of the spindle has to be removed. The differential accumulator shown in Plate 44 was designed by Messrs. Thompson Boyd and Co., of Newcastle-on-Tyne, and the writer, to work his hydraulic riveting machine, of which a large number are now in use, doing the very heaviest work.

In cases where the application of hydraulic pressure is thoroughly carried out, and an accumulator erected large enough to supply the entire works, the hydraulic machines for riveting, punching, forging, and pressing, &c., would each individually be much cheaper than any other machines at present in use for the same purposes. Even as at present applied, including a separate accumulator and pumps for each machine, they are only very little more expensive than machines driven by boiler or engine power for doing the same work; and considering also the saving in foundations, of which practically very little are required for hydraulic machines, they are still more advantageous, even in respect of first cost only, independent of the constant saving of fuel and skilled labour in working.

In reference to friction, the very careful experiments made by Mr. Hick show clearly the advantages of hydraulic machines, the friction of leather collars for rams of 4 inches diameter being found in the generality of cases to be only 1 per cent. of the total pressure upon the ram, and only $\frac{1}{2}$ per cent. for rams of 8 inches diameter. With regard to the depth of the packing leather, experiments have shown that this makes no appreciable difference in the amount of the friction; and in some old leather collars now exhibited to the meeting it is clear that all the friction has taken place at one portion only of the collar. These are important practical results; and in the case of machines adapted to riveting by hydraulic pressure, the saving in total pressure required to overcome the friction, as compared with that in a steam riveting machine exerting the same closing power on the rivet head, has been found by indicator diagrams taken from both classes of machines to be 3·10 tons, this difference being consequently available for closing the plates more effectively by the hydraulic machine. In Fig. 18, Plate 50, is shown a full-size section of the leather collar A A used for the

accumulator shown in Plate 44, and for the hydraulic machines worked by it; the collar is secured by the gland B within the recess in the hydraulic cylinder C, a thickness of hemp bedding D being placed between the leather collar and the end of the gland. A brass cup-ring E is inserted within the collar to ensure keeping it open, or a gasket of plaited hemp is employed for the same purpose. At the part where the greatest wear of the leather collar would take place, from the friction of working against the ram or spindle F, a brass guard-ring I is added outside to protect the leather. The friction of the packing leathers and their wear and tear are a frequent cause of hesitation in adopting hydraulic machinery; but by using really good leather, and carefully moulding and fixing the collars in their places, and by giving proper attention to the wearing surfaces, and covering them with brass or gunmetal, as shown at I, Fig. 18, more especially in those cases where the leathers themselves move, there is little or no trouble with the packing leathers. If the surface on which the leathers work is allowed to get dirty, they will become worn as fast as an ordinary engine slide-bar. Under a pressure of 1700 lbs. per square inch however, leathers have been at work eighteen months on the accumulator spindle, and in some cases accumulators are working with ordinary gasket packing without leathers; and the packing, whether leather or hemp, is certainly a smaller item of expense than leather belting would be for transmitting the same driving power.

As regards the best initial pressure to employ in the application of hydraulic power to shop tools and machinery, there are several points to be considered. On the one hand, in addition to the fact that the friction increases in direct proportion to the pressure, there are other causes which render advisable as moderate a pressure as possible. If a very high initial pressure is used, the area on which it acts must be proportionately reduced in order to keep the total pressure down to the amount that is required for performing the average operations in engine works; this renders the attachment of dies, cups, moulds, shears or eye-bolts, difficult to be accomplished in such a manner as to ensure sufficient strength. The difficulty of

keeping the joints tight also increases in considerably more than the direct ratio of the pressure.

On the other hand there are strong reasons in favour of as high an initial pressure as is consistent with a moderate amount of trouble with joints. Safety need not be considered, since no accidents can as a rule happen with machines worked by water pressure. The high pressure is not so important for fixed machines, such as forging presses, stamping machines, and fixed riveting and punching machines, as for portable machines where saving of weight is so great an object. With higher pressures, less water is used in the same ratio in which the pressure is increased, and consequently less capacity of pump is required, and a smaller accumulator with less load upon it is sufficient. In practice no difficulty whatever is experienced in working machines at 1000 lbs. per square inch; and in the large majority of the machines working at 1500 to 1750 lbs. per square inch no trouble is experienced.

In the successful and extensive application already made of water pressure for moving dock-gates, sluices, and bridges, the chief advantage which this means of transmitting power is considered to possess is the facility for distributing the power over a large area, and applying it at the exact point where required, and in the exact quantity, whether of high or low intensity. To have just the amount of power required, and no more, is the difficult object aimed at in transmitting power to machines generally. In place of the serious loss of power that is caused by friction of shafting and gearing, the transmission of power by water pressure involves only the loss arising from the friction of the pumps, accumulator, and press cylinders, and of the water in the pipes. Ship yards and boiler and bridge yards, all of which are now often combined together, are so large in extent, and the area over which power has to be distributed is so great, that the circumstances become similar to those of dock works, where water pressure is already so satisfactorily established. In such cases the transmission of power by shafting is cumbersome and expensive, while the use of separate engines or sources of power at different points is again both expensive and wasteful.

The application of water pressure for driving shop machines appears to the writer to be as suitable as for the machinery of dock works, on account of the small number of working parts, safety of working, lower cost of construction, saving of foundations, and absence of noise; and also because by this means the power can be conveyed to considerable distances without any material loss of effect. The accumulator can be made to act as a governor to the engine, controlling the expenditure of steam according to the requirements of the work; and with suitable furnace gear to the boiler it can also be equally efficient in regulating the quantity of coal supplied.

In the machines employed for all classes of wrought-iron work, including shipbuilding, girders, bridges, boilers and forgings, all that is generally required is a comparatively small reciprocating motion, combined with great power at a given point. This is obtained at present by means of a complication of shafting and gearing or belting, which gives generally only a uniform fixed range of motion in the punch, cutter, or riveting die, without any means of varying this range to meet immediate requirements. But for any machine in which considerable power and a reciprocating motion only are wanted, there seems no more direct means of transmitting the power than by the application of water pressure.

There are however practical conditions to be observed in order to ensure success in the use of water pressure; and one point is not to aim at effecting too much in one machine, as has been done in some cases where great ingenuity and time have been expended in perfecting small hydraulic tools which combine in themselves both pump and tool. Such tools are very efficient whilst properly and carefully handled, and whilst everything about them is in good order; but they are too delicate and small to be considered satisfactory applications of the principle of water pressure. An example of this class of tool is given in Fig. 13, Plate 46, showing a hydraulic tube-expander designed by the writer some years ago, which in its action was perfectly satisfactory; but it did not prove practically successful, owing to the care required in its working. With the advantage of subsequent experience in the construction

of joints, the writer is of opinion that this and similar tools when worked in connection with an accumulator would be of great service. In the tool shown in Fig. 13 the water was pumped in at A direct from a small hand-pump, and forced outwards the ram B, which drew the hexagonal wedge C through the dies D, thus expanding the tube in the hole in the tube-plate E. Upwards of sixty tube ends per hour were finished with ease, and when the holes and tubes were true a first-class job was the result. The pressure used was $1\frac{1}{2}$ to $1\frac{3}{4}$ tons per square inch.

The subject of machine riveting by means of hydraulic pressure attracted the writer's attention a few years ago, in connection with some indicator diagrams taken from a steam riveter at Messrs. Hawthorn's works at Newcastle; and also in consequence of a desire to secure a better class of work in riveting up the large boilers now used for high-pressure marine engines, having plates in some cases $1\frac{1}{4}$ inch thick with $1\frac{3}{8}$ inch rivets. These diagrams were taken for the purpose of ascertaining the lowest possible pressure that would make a good rivet, with a view to working out a proposed portable arrangement of hydraulic riveter, the success of which depended upon the limit of strength of a steel bolt of rather smaller diameter than the rivet to be closed. Much time and ingenuity were devoted by Messrs. Thompson and Boyd to working this out; it was attached to the work to be done on a somewhat similar principle to Mr. McFarlane Gray's steam riveter, but involved the extra difficulty of requiring the connecting bolt to stand a steady pull of at least 13 tons, whereas in the steam riveter the benefit of a series of lighter blows sharply given was obtained. The hydraulic riveter however possesses the advantage of having within itself the means of keeping it cool enough for the men to handle.

In Fig. 4, Plate 45, is shown the indicator diagram obtained from a steam riveting machine, the moving die A advancing in the direction of the arrow to close the rivet. It is seen that to start the machine a total pressure of 9 tons was required on the piston, diminishing when the inertia was overcome to $3\frac{1}{2}$ tons at

the place where the advancing die first touched the point of the rivet; the pressure then gradually increased up to 21 tons until the rivet was made. The vibration of the dolly is shown by the dotted line B B. The line C running upwards from 21 tons shows the second blow of the riveting die, which is given with more impetus, as there is no previous closing up of the rivet and no cushioning of the steam. Some indicator diagrams were afterwards taken by Messrs. Thompson and Boyd from their hydraulic riveting machine; but the indicator was in this case only hastily constructed, and its friction was considerable. These diagrams however showed three important points:—the small amount of friction on the whole machine—the combined effect of the momentum due to the fall of the accumulator, as well as of the steady pressure due to the load—and the small amount of vibration of the dolly; in the steam diagram, Fig. 4, this vibration is seen to be $\frac{1}{2}$ inch, but in the hydraulic diagrams it was only 1-20th inch.

From the consideration of the indicator diagrams obtained in steam riveting, the writer was led to design a hydraulic riveter, of which the chief features were a high initial pressure, the use of an accumulator, and if possible a small steam boiler and pumps combined, so as to render it pecuniarily profitable to keep the riveter at work continuously, without having to keep the shop engines running. In the most recent arrangements the flame from the rivet-heating furnace raises enough steam in the boiler to drive the accumulator force-pumps and a considerable quantity of other machinery. The first of these hydraulic riveters was made by Messrs. Thompson and Boyd, by whom it has been worked with great advantage for several years, and they have since manufactured a large number of them. The machine is shown in Figs. 5 to 10, Plates 45 and 46; and Figs. 11 and 12 show the details of the valvebox and ram. The water from the accumulator is admitted to the cylinder and exhausted from it through the same aperture A, Fig. 8, by means of a simple hydraulic valve of ordinary construction, shown in the sectional plan, Fig. 11. The water enters at B, which tends to keep the inlet valve C shut, the spring D also doing this until the pressure from the accumulator begins to act. When the water is to

be admitted to the cylinder, the valve C is opened by the hand lever E and is kept open by hand until the rivet is closed, or it is wished to stop the ram at any portion of its stroke. The exhaust valve F is kept shut by the pressure of the water entering the cylinder, and at other times by the spring D. When it is desired to draw the ram back, the exhaust valve F is opened by pushing the hand lever over the reverse way to that for opening the inlet valve C; this allows the exhaust water to flow back to the pump cistern, and a small portion of it is allowed to flow upon the die to cool it, through the pipe shown at G in Fig. 8. The ram H is drawn back by means of the small drawback cylinder J, Fig. 12, which is arranged within the ram itself and is in constant communication with the accumulator through an inlet at K. The handle E unships readily, and is taken away by the man whenever absent from the machine. By this plan of valves in combination with the drawback arrangement the greatest possible control is obtained over the machine, the ram being motionless as soon as the hand lever is released or removed from the valves. The power of control thus obtained is of the greatest importance in riveting and punching, to prevent blind holes and unfair work; and it does away with all necessity for the care usually required in regard to the length of the rivets, as the machine shortens its stroke to suit a long rivet, while if the rivet is too short the machine still closes the plates equally well by extending its stroke. With the high pressure of water employed, the small diameter of ram, only 8 inches, is sufficient to give the same pressure on the riveting die as is obtained in a steam riveter with 36 inch cylinder; and this is an advantage in rendering the machine easily got at and convenient for the work to be riveted. The wedge-shaped fastening of the die in the dolly, as shown at L in Figs. 8 and 10, obviates the necessity for any thickness of metal over the fixing pin ordinarily employed to keep the die in its place; this is of importance in extending the applicability of the machine in riveting flanged and angle-iron work.

It has been urged as an objection to machine riveting that a shoulder is formed on the rivet between the plates; this is liable to be the case where the closing is effected by a sharp blow, but in no

instance has it occurred, when, as in the case of hydraulic riveting, the rivet is closed by a pressure which is in its nature a combination of a blow and a squeeze. This is a great advantage, for when a rivet has a shoulder formed on it between the plates it cannot be got out except by drilling, and the plates being kept open the tightness of the joint depends entirely on the caulking. The combined character of the pressure brought to bear on the rivet by the hydraulic machine, and the power of retaining that pressure for some time, are of advantage in very thick boiler work; and when used for closing the plates all round, the hydraulic riveter gives the men an opportunity of tightening up the bolts and nuts. The wear and tear on the machine itself is very slight, and the work is done in perfect silence and with no vibration of the machinery.

As to speed of working the machine, the classes of work it has hitherto been principally employed upon have been compound marine boilers of the heaviest description and light portable agricultural boilers. The former are very heavy and difficult to handle, and the latter are of rather a complex kind, but in both cases the hydraulic riveter has proved satisfactory to the users. In heavy work the machine has put in 900 to 1000 $1\frac{1}{8}$ inch rivets in 1 inch plates in an ordinary day's work of ten hours; and the portable boiler work is done at an average of 7 rivets per minute, one machine having put in 500 rivets per day, as an average of several weeks, including all stoppages while the men were off work; and if accumulator power is provided of sufficient capacity, there is no difficulty in making the machine put in 15 rivets per minute. An accumulator and pump power are supplied with the riveter, of sufficient capacity to meet the demands of average work; and the result is found very economical merely from a wages point of view, independent of the general economy of the system. The hydraulic riveter possesses also the great advantage of certainty and uniformity in the work done, every rivet being closed by it with the same pressure, since no water can get into the cylinder except through the accumulator, and then only at the pressure to which the accumulator is loaded; but in all steam riveters the pressure obtained in the cylinder fluctuates with the pressure of steam in

the boiler. No fear exists in this country as to freezing of the water employed in the press. On the Continent glycerine is used or methylated spirit; and the liquid being used over and over again is not expensive. Ordinary drawn wrought-iron pipes are employed for conveying the water, and are laid 6 or 9 inches underground.

The next class of machine to be noticed is the portable or moveable class; and Fig. 14, Plate 47, shows one of the heaviest moveable machines for riveting furnace rings, beams, girders, &c. The strain of closing the rivet is here taken by the two tension rods M. The crossheads N N are loose on their centres, and the concave and convex ends P meet first, and act as a fulcrum while the rivet is being closed. The distance between the crossheads can be adjusted by the nuts R on the tension rods M; and eye-bolts S are placed at intervals for convenience of suspending the riveter about the work on which it is employed. In Figs. 15 and 17, Plates 48 and 49, is shown another form of the portable riveter, without the crossheads, the dies being here in line with the ram. The longitudinal section, Fig. 17, shows the arrangement of the drawback cylinder within the ram, and the valves are shown in the transverse section, Fig. 16; in both these respects the portable riveters are similar to the fixed machine previously described. Some of the various classes of work to which the portable riveter can be applied are illustrated in Plate 51; in Fig. 22 the machine is shown riveting a box girder, in Fig. 23 the bottom ring of a portable boiler or superheater, in Fig. 24 the expansion ring in the flue of a marine or Cornish boiler, and in Figs. 26 and 27 the spokes and tyre of a railway wheel.

In Plate 53 is shown the proposed method of applying the portable riveter to ship construction, one half of the ship being represented in dock and the other half on a slip, for convenience of illustration. The machine without the crossheads, shown in Plate 49, is represented riveting the frames of a ship before erection; this machine is easily converted into one for punching or bending and straightening. Although the portable riveter is considered capable of doing nearly every portion of a ship's frames,

and the cellular bottoms of large vessels, and a great variety of general work in a boiler or bridge yard which a fixed machine cannot do, yet it does not overcome the plating difficulty that occurs in ship work more especially. In the hydraulic riveter referred to before as experimented upon by Messrs. Thompson and Boyd, round and uneven surfaces were the cause of much trouble; the necessity for perfect fairness in the work was also a great difficulty, especially as the margin of safety in the tension rod was not large to begin with. There is a system of plating which is sometimes adopted, shown in Fig. 25, Plate 51, with narrow cover strips over the butt joints of the plates, whereby about 40 per cent. of the riveting might be done by the machine, the adjacent rivet shown dotted in Fig. 25 being put in by hand; but there are many difficulties in doing even that proportion by the machine, especially from the circumstance that, in order to ensure fair work, a ship is generally nearly all plated before riveting commences.

Another form of moveable riveter was suggested by Mr. F. C. Marshall at Jarrow Engine Works to rivet some very large marine boilers, 16 ft. 8 ins. diameter and 23 feet long, with $1\frac{1}{4}$ inch plates, the joints being double-riveted with $1\frac{3}{8}$ inch rivets. This machine is shown in Figs. 28 to 30, Plate 52, and consists of an adaptation of the hydraulic cylinder, drawback, and valve gear, to two long girders A, one placed inside the boiler to support the dolly B, and the other outside to support the hydraulic cylinder C, which is connected by jointed pipes to the main from the accumulator working the ordinary hydraulic riveter in the shop. The two girders are coupled together at the ends of the boilers by screws, and are suspended level with the centres of the boilers to be riveted. The outside girder is made double, for the riveting cylinder to slide between, as shown in the side elevation, Fig. 30; and by means of the hand lever D the cylinder is drawn aside, to make way for the insertion of the rivet, and is then pushed forwards again into the position for closing the rivet. The dolly on the inside girder is shifted by hand, and is secured in the proper position on the girder by a tightening screw. Every rivet in the shell can be put in by this machine, and when the boilers are too heavy for the crane power

at command, this arrangement is found very useful, the boilers being then carried on rollers and pushed round by jacks, as shown in Fig. 28.

One point in connection with portable hydraulic machinery, which has been attended with much trouble and difficulty, is the means of conveying the water pressure to the machines in the changing positions in which they have to work; and when the pressure is great and the machines are handled by the roughest class of men, this is not an easy task to accomplish. Two forms of universal joints for the connecting pipes to moveable machines are shown in Figs. 19 to 21, Plate 50, which are now very satisfactory, each being made water-tight with leather collars A A; the large moveable riveter shown in Plate 52 was worked with these joints, and no trouble was experienced with them. A length of copper pipe twisted spirally forms also a good elastic connection.

In the application of hydraulic power for driving machines and tools, the writer's experience is that the only correct method is to carry out the application thoroughly and completely, and not to follow any intermediate course; and although there are already many cases in which this plan of working is in use to some partial extent, as in the employment simply of a hydraulic riveter with its accumulator and pumps, it is highly desirable to start from the commencement upon this plan, by erecting a powerful engine, pumps, and accumulator, and laying down water-pressure mains over the entire works. Such mains should be laid on a systematic plan like those for supplying gas or water, and should be brought alongside the several ships, bridges, or boilers in process of construction; and then branches should be carried from the mains to transmit power to the various individual machines and tools, enabling each to do the required work at any moment, without any power being uselessly consumed whilst the machine is standing. The engine and boiler would then have no more work to do than to maintain a supply to the accumulator equivalent to the work actually performed. Plate 54 illustrates a proposed general arrangement, showing how in bridge-building, ship-building, engine works, or

graving docks, this power can be applied to shears, dock gates, boiler riveting, &c.

Although the application of water pressure to tools has been limited at present to a few classes of machines, there does not appear to be any insuperable difficulty in extending this plan to other classes of work, such as planing or slotting machines, and the larger class of lathes. For quick revolving machines, such as small lathes and drilling machines, some hydraulic centre of rotary motion such as a turbine or water engine would have to be provided, to drive a small quantity of shafting; and in the erection of some wrought-iron bridges the drilling has been done by multiple drills, driven by small turbines worked at high pressure. For the working of bending presses for armour-plates &c., moulds for forgings, and cranes, the main accumulator would be sufficient. There is a great advantage in working direct from an accumulator for flanging and bending plates, as the quicker action often saves a heat and enables the plate to be got off the mould before contracting on it too fast. The use of hydraulic pressure to press plates against multiple drills is well known; and even in the foundry, in addition to saving a large amount of labour in lifting the raw and finished material, water pressure can be applied for compressing fluid metal, which it is well calculated to perform with advantage. A very large amount of forging is done on this plan abroad, more especially at Borsig's works at Berlin, where one of Haswell's hydraulic forges does an extraordinary quantity of work; and in smaller establishments there is a desire to adopt a similar mode of working. Although the hydraulic system appears expensive at first, it must not be judged by the cost of a single set of water apparatus or one forge hammer, as in that case the pump and accumulator represent as much as half the total cost; but it is clear that where accumulator power is supplied for an entire works, there is no class of machinery so cheap and with so few working parts.

In conclusion it may be remarked that, in thus treating the application of hydraulic pressure to shop tools generally, numerous requirements and improvements in detail have been passed by without notice. One defect however to be noticed is that, since the

greatest effort of work in a hydraulic machine is generally required through only a very small portion of the stroke, the water used during say 70 or 80 per cent. of the stroke of the ram is drawn from the accumulator, into which it has been pumped under a heavy load, simply to fill the cylinder of the machine, whereas water at no pressure would answer that purpose equally well. The waste of power thus occasioned can be saved by several means, and has been the subject of many experiments by the writer; and any such plan, if effected, will cause large economy where the system is completely developed, and another advantage gained will be in speed. The difficulty in working out these details lies chiefly in the necessity of avoiding complication; and when the system advocated is more completely developed, it will then answer to adopt these refinements; but unless the whole apparatus is made self-acting, and certain, and independent of skilled labour, it cannot be considered completely successful. Even with this defect, which is only peculiar to such machines as riveting machines and does not apply to the same extent to others, this system of transmitting power is at once convenient and economical.

Mr. Tweddell exhibited a specimen of the portable hydraulic riveter, together with a number of sections of riveted work planed down to the centres of the rivets, for showing the very perfect manner in which the riveting was done by the hydraulic machines. He showed also specimens of the leather collars that had been in use for a length of time for packing the rams of the accumulators and of the hydraulic cylinders in the various machines.

Mr. L. Olrick enquired whether any attempt had been made to use the ordinary pressure of 60 to 70 lbs. per square inch obtained from the water supplied by the waterworks in towns, so as to work by this means riveting and other hydraulic machines, without

the necessity of employing an accumulator and special pumping machinery, which would otherwise restrict the application of the portable hydraulic tools.

Mr. J. McFarlane Gray mentioned that his experience with the portable steam riveter, to which reference had been made in the paper, had been that it was much easier to design and construct the machine than to apply it to practical work. In the case of shipbuilding, on account of the multiplicity of beams and planks crossing one another in all directions in a vessel in course of construction, the time and trouble spent in shifting the steam-pipe connections for moving the riveter from hole to hole were found to be so great in practice as to counterbalance the advantages of the machine; and there was also a considerable proportion of the work to which a machine would not be applicable. An idea had been entertained of applying the portable steam riveter as a rock-boring instrument for mining operations, and one had been sent out to South America for that purpose; but it had been lost in an earthquake before reaching its destination, and nothing further had been done in the matter. The hydraulic riveter now described, although more costly in the first instance, seemed to him likely to prove more successful, as it appeared to possess several points of advantage, one of which was that the use of water would keep it cool in working. In the steam riveter the die could not be got to stand with any certainty, as it became very much heated by the rapid blows in closing a rivet, and the entire instrument was made very hot by the steam working it; sometimes a die would last a month before requiring renewal, and sometimes only an hour, and no dependence could be placed upon the durability of the material of which the dies were made. To obviate the heating of the tool when worked by steam, compressed air had been employed instead by Messrs. Cochrane for working one of the portable riveters; and another of them, worked in the same manner, was still in use for certain descriptions of riveting at Messrs. Forrester's works in Liverpool. The weight of that riveter was only 22 lbs., the cylinder being $1\frac{1}{4}$ inch diameter and 9 to 12 inches stroke, worked with 60 lbs. pressure of air; it riveted together five

$\frac{1}{2}$ inch plates for bridge work with $1\frac{1}{8}$ inch rivets, and made a very good job. There was no difficulty in holding it up to the rivet while in action, although the connection with the dolly by a bar inserted through the adjacent rivet-hole was now done away with, and the riveter was merely held on the point of the rivet without any attachment whatever. In the hydraulic riveter he thought much ingenuity had been displayed in the plans contrived for fixing the machine in a suitable position for doing its work in the different situations where it would have to be employed; and the fact of its being applicable to closing the plates before riveting would be a great advantage, which was much needed in the application of his own portable riveter.

Mr. C. Cochrane said he had first seen the portable steam riveter at work at the Dublin Exhibition in 1865, and had then employed it at the Woodside Iron Works at Dudley, where it was in operation for a few months, after which it was employed experimentally in the erection of the Runcorn Bridge, being worked there with compressed air.

Mr. D. Adamson observed that, in addition to the difficulty of applying a portable riveting machine in all the positions in which it would have to work when employed upon boiler making and shipbuilding, he had been led to the conclusion that both in steam and hydraulic riveting machines a very large proportion of the power was wasted, on account of the riveting die having always a fixed range of motion, during the greater portion of which it performed no useful work, only about the last 3-16ths inch of the stroke being effective ordinarily in closing the rivet head. The length of stroke that was really wanted for the die was only such as would allow of getting the tool clear off the rivet head when completed, and placing it over the next rivet to be closed; but the actual stroke, made under the full pressure of the steam or water, was so much longer than this necessary amount, that he considered there must always be a serious loss in applying either steam or hydraulic riveting machines; and another objection was that too much reliance had still to be placed upon the skill of the workman using the machine. Moreover as the size of the rivets might be $\frac{3}{8}$ inch diameter in one

piece of work, $\frac{3}{4}$ inch in another, and $1\frac{1}{8}$ inch in a third, it would be necessary to change the accumulator pressure or the boiler pressure accordingly; and if this had to be done several times in a day, it would become a great trouble. He had seen some riveting machines produce most injurious effects upon rivets of large diameter, through imperfect workmanship owing to deficiency of pressure for properly closing the rivet. From these considerations he had for many years adopted an application of a steel-yard to riveting machines, by which the exact pressure to be put upon the rivets was correctly adjusted, and the workman had only to see that the load so fixed was lifted off the buffing block by the pressure put upon the rivet, without its being in his power to exert any greater force upon the rivet. With this arrangement the exact amount of force that was most suitable for the purpose was ascertained and employed, and by this means he had obtained better results in the character of the work than from either steam or hydraulic riveting machines with a fixed die. The use of unknown amounts of force he considered a more serious objection than even the waste of power attending steam and hydraulic riveting machines, because the work done would be irregular in character, disappointing to the maker, and possibly disastrous to the user. Hydraulic power in particular he thought was necessarily very expensive and extravagant for application to shop tools, such as planing, punching, and riveting machines; and having given some attention to the construction of hydraulic machines, he had come to the conclusion that they would not yield results at all commensurate with the expenditure of power, so great an amount of the power being utterly lost.

Mr. Tweddell said, in reply to the enquiry about applying the waterworks pressure in towns for working hydraulic machines, he had not made any attempt in that direction, not that it could not easily be done, but because such a plan possessed no advantages over the use of steam power for performing the same work. A hydraulic riveting machine had been worked at 200 lbs. pressure per square inch, and had answered as well in closing the rivets as if a higher pressure had been used; but the size of cylinder and pipes was then very considerable, and the consumption of water was greatly

increased. All that was necessary, so far as the character of the work done was concerned, was to get the required pressure upon the rivet head, and to ensure the same amount being exerted on each rivet; this was done by the accumulator, which was also a ready means of exerting the pressure. But for economy of work, the highest pressures that were compatible with keeping joints tight without undue trouble and expense were found the best, and now no undue trouble was experienced in the use of the high pressures employed for these hydraulic machines. There had certainly been a great deal of trouble in maturing the arrangements for the successful use of such high pressures, but not more than was to be expected in carrying out such work; and nearly every difficulty as regarded the pipes and connections had now been satisfactorily overcome. Allusion had been made in the paper to the loss of power, amounting in many machines to a considerable percentage, which was caused by using the full accumulator pressure during the whole of the stroke, in the hydraulic riveting machine especially, while the full power was only required just at the end of the stroke; he had several times endeavoured to overcome this, the only objection to that application of hydraulic pressure, and had succeeded in doing so if it was required. It was of course very simple to admit a lower pressure of water during the first portion of the stroke, while little or no work was being done except crushing the rivet, and afterwards by a sort of compound-cylinder arrangement to admit the high-pressure water from the accumulator, for performing the last part of the stroke; but the practical objection to this plan was the introduction of extra complication in handles, valves, and leathers, rendering the working of the machine dependent on the judgment and skill of the men. No machine depending upon the judgment of the men would prove of any practical value; and if this refinement were to be adopted, it would have to be done by some self-acting gear. For the purpose of affording the means of altering the pressure exerted by the hydraulic riveter according to the diameter of the rivets, he had designed an accumulator in which the load giving the pressure was regulated by a lever, which removed any proportion

of weight required to obtain reduced pressure, so that the load could be readily adjusted as desired. The use of an accumulator acting under a known load was itself a guarantee that the exact pressure corresponding to that load was exerted in the cylinder of every hydraulic machine supplied from the accumulator; and there was thus no uncertainty whatever as to the actual pressure put upon the rivets by the hydraulic riveter, as no other pressure could be obtained from the accumulator while working under the same load. The amount of work performed with the hydraulic riveter, which had been stated to be 500 rivets per day, was not the result of only a single day's trial, but was the average of six weeks' work with one of the machines at Messrs. Marshall's works at Gainsborough, including short and off days; as many as 1000 rivets could be put in by the machine in a day, and it had put in $\frac{5}{8}$ inch rivets at the rate of 10 to 12 per minute.

Mr. L. Cooper mentioned that at Mr. Mendel's new warehouse in Manchester he had lately adopted a new mode of working the hydraulic packing presses, cranes, and hoists, dispensing altogether with the ordinary plan of gearing, shafting, small force-pumps, and accumulator. This was effected on the plan of Mr. Wilson of Patricroft, by means of two pairs of horizontal high-pressure engines, each pair working direct a set of four plunger-pumps, one from each end of the two piston-rods, and drawing water from a tank. The pumps of one pair of engines forced the water along a main line of pipe at a pressure of 1500 lbs. per square inch, which gave power enough to raise the rams under the tables of the packing presses through more than three quarters of the length of their stroke, in making up bales of goods; the other set of pumps, having plungers only half the diameter of those in the first set, forced the water along another main under a pressure of 3 tons per square inch, which raised the press rams through the remaining quarter of their stroke, completing the bales to the required size. The presses, twenty in number, were connected with the mains by a series of branch pipes, and each press was provided with three valves, one for admitting the low pressure, another for the high, and the third an exhaust valve for returning

the water to the supply tank through an additional main, that the water might be used over again. The engines were entirely self-acting, and each pair was controlled by a hydraulic regulator, having a small plunger loaded with a spiral spring and exposed to the pressure in the main; this was connected by a slotted rod to the lever of the steam throttle-valve, which was opened by a weight on the opposite end of the lever, the tendency of the regulator spring being to close the valve; but as the pressure increased in compressing a bale, the plunger of the regulator rose and allowed the throttle-valve to be gradually opened by the weighted lever, giving the full pressure of steam when the extreme pressure was attained in the press. Each pair of engines was also provided with a hydraulic governor, having a piston loaded by a weight to the required limit of water pressure, and connected by a slotted rod to the lever of the same steam throttle-valve, which was closed by the rising of the piston; by this means the limit of pressure was prevented from being ever exceeded, and on completion of the work at either the presses or the cranes or hoists the engines were stopped by the closing of the throttle-valve; but as soon as the pressure in the main was reduced, the engines started again under the control of the regulator, the engineman having therefore little to do beyond attending to the boiler. With this plan no difficulty had been found in working eight presses simultaneously, four of them with the low pressure and four with the high; and the average time occupied in completely compressing a bale was about 17 seconds. A similar plan he suggested might be applicable in the hydraulic riveter, to avoid making the entire stroke under the full pressure of the accumulator, reserving the latter for the actual closing of the rivet in the last portion of the stroke.

The PRESIDENT remarked that the application of hydraulic force to machines was a question involving several considerations, and it appeared to him that the application to riveting was not one of the most promising, inasmuch as a great deal of power must be lost, especially when accumulators giving a very high pressure were employed, because the working resistance during the greater portion

of the stroke was practically nothing, and the force must be consumed in frictional resistance of the valves; this disadvantage was however balanced by advantages derived from the great and steady pressure at the end. More attention he thought might advantageously be directed to other applications, where there was a continuous steady resistance to be overcome, and where hydraulic force might consequently be applied with the greatest advantage, as in the case of the hydraulic planing machine which had been seen in operation on the previous day at Messrs. Clay Inman and Co.'s works at Birkenhead.

He proposed a vote of thanks to Mr. Tweddell for his paper, which was passed.

The following paper, communicated through Mr. George H. Daglish, of St. Helen's, was then read:—

DESCRIPTION OF A COAL CUTTING MACHINE WITH ROTARY CUTTER, WORKED BY COMPRESSED AIR.

By Mr. ROBERT WINSTANLEY, of Manchester.

At no period in the history of the coal trade has a greater want been felt than at the present time for the substitution of machinery in place of manual labour in the working of coal; and never since the time when one of the earliest recorded attempts to construct a coal-cutting machine was made by Michael Menzies in 1761, have the difficulties experienced by coal proprietors been greater than now, as it is almost impossible to make production keep pace with the demand, and the difficulty is further increased by the diminished production which accompanies a high rate of wages. Any improvement therefore in the working of coal mines, which will increase the quantity of coal got and diminish the cost of production, and at the same time relieve the miner of the most laborious and dangerous part of his work, must be a benefit not only to those immediately interested in the work, but also to the consumers generally.

The principal objects to be gained by the application of machinery to coal-cutting are, first, the production of a greater quantity of coal at a lower cost than by hand labour; secondly, the saving of a large quantity of the coal, which in the ordinary mode of holing or undercutting by hand labour and blasting with powder is broken up into slack and dust; and thirdly, the removal of the danger to which the miner is exposed in holing or undercutting. Some advantage also results from forcing a certain quantity of fresh air into the working places, which is discharged from the exhaust of the cylinders when compressed air is employed for working coal-cutting machines: although too much stress has occasionally been laid upon this advantage.

The Coal-Cutting Machine described in the present paper has been worked daily or nightly for nearly two years at the Platt Lane Colliery of the Wigan and Whiston Coal Co., in a seam of coal known by the name of the "Pemberton Little Coal" or "Pemberton Yard Mine." This coal is about 2 feet 4 inches in thickness, and is so hard that it was with the utmost difficulty men were obtained to work it; on one occasion the seam stood idle at this colliery for some time, because colliers could not be got to work in it, and it has always been necessary to pay a higher price for getting this coal than for any other seam of coal worked by the same proprietors.

The machine, which is the invention of the writer and Mr. Barker, is shown in Figs. 1 to 4, Plates 55 to 58. Like most other coal-cutters it is driven by compressed air, which is conveyed down the pit shaft and along the main roads and drawing roads in iron pipes, and from the end of the drawing road to the machine in an india-rubber hose pipe of 2 inches diameter. The frame of the machine is about 6 feet in length, Fig. 1, and is supported on flanged wheels which run on the ordinary tramway of the mine; the gauge in this instance is 2 feet, but it can be varied to suit other gauges as may be required. On the front part of the frame are two oscillating cylinders A A, Figs. 1 and 2, of 9 inches diameter and 6 inches stroke, provided with ordinary slide-valves. The piston rods are connected to an upright crank-shaft C, Fig. 4, on the bottom end of which is a driving pinion B, shrouded at the top, and having only five teeth, as shown in the plan, Fig. 5, Plate 59. The teeth of this pinion gear into the teeth of a spur wheel D, which is also the cutting wheel, and is 3 feet 6 inches diameter; the driving power is thus applied with the greatest mechanical advantage, that is, directly on the circumference of the cutting wheel. The cutters are fixed in the circumference of the wheel, one in every cog or tooth, their points projecting 1 inch beyond the teeth; the mode of fixing them is shown in Figs. 6 to 8, and there are three patterns of cutter, as shown in Figs. 9 to 12, which are arranged successively round the cutting wheel.

The cutting wheel revolves at the end of an arm E, Figs. 1 and 4, consisting of a broad flat plate, at the opposite extremity of which is a toothed segment or quadrant, actuated by a worm and handwheel F, whereby the arm carrying the cutting wheel can be turned partly round in its bearing in the frame of the machine. Before the machine commences to hole in the coal, the cutting wheel is under the back part of the frame, as shown dotted at G in the plan, Fig. 1, almost touching the straight face of coal; and on starting the engines the attendant by turning the handwheel and worm F causes the cutting wheel gradually to hole its way into the coal, until the arm E is at right angles with the frame of the machine, as shown at D in the plan, Fig. 1, and the transverse section, Fig. 4. In this position the cutter is holing about 3 feet in depth from the face of the coal; and it can be placed in any position to hole less than this depth if required.

As soon as the cutter has worked into the coal to the full depth, in the position shown at D in Fig. 1, the machine is drawn along the face of the coal as it holes or cuts its way, throwing out the small coal or slack between the tram rails upon which the machine runs. The thickness of the holing or groove cut out is 3 inches; this thickness however can be reduced if desired by the use of a thinner cutting wheel. There is no traverse motion on the machine, as it is considered simpler to draw it along the face by means of a small crab turned by a lad at the end of the working face. When the holing of the entire length of the face is completed, the cutting wheel is brought back to its original position underneath the frame of the machine, by means of the worm and handwheel, and is ready for beginning to hole at the commencement of the new face as soon as the coal already holed has been removed.

The chief advantages in this machine are that the swivelling movement of the arm carrying the cutter enables it to cut or hole its own way into the coal, the depth of cut increasing from nothing up to about 3 feet; and by the same movement the cutter is brought back underneath the frame of the machine when not at work. It will also be perceived that when the cutter is in this

position, drawn back underneath the frame, it can be taken through any narrow roads or parts of the mine, without the necessity of removing the cutter from the machine, the space required for the machine to pass being only the width or diameter of the cutting wheel, which with the cutters is 3 feet 8 inches. Again, were it not for this arrangement, a portion of the coal would have to be cut out by hand labour for the purpose of inserting the cutting wheel, unless the machine were started at the corner of a pillar or what is called a "loose end." An important advantage in this machine is that the power to drive the cutting wheel is applied direct on the circumference of the wheel; this mode of gearing also allows the small pieces of coal or slack to fall through to the bottom, so as not to lock or clog up the teeth of the machine.

The average rate of holing is from 25 to 30 yards advance per hour, according to the nature of the coal the machine is holing; but the rate is not practically a matter of much importance, as the great points to be considered are the amount of work a machine will do regularly, and the way in which it does it. This machine has frequently cut the whole length of the face of 120 yards in a night, or between 7 p.m. and 4 a.m., including all stoppages for meal times and changing cutters &c. In the same mine 5 yards per day or $\frac{2}{3}$ yard per hour is much above the average work for one man with the pick; and under ordinary circumstances it is considered the work done by the machine is equal to that of thirty men.

The machine works in the night, the coal being removed by ordinary manual labour in the day. No blasting is used in this mine, the coal falling by its own weight after it has been holed by the machine; this however would not probably be the case if the face were short, and if the holing were not made of the same width for the full depth. The roof of the mine is ordinary laminated shale, and the underlying stratum very hard fire-clay, nearly approaching rock; the dip of the strata is about 1 in 6, and the machine holes up bank. The average pressure of air at the machine is 25 lbs. per square inch.

For more than six months the machine has had little or no repairs, and the practical advantages found in its working are as follows.

First, that without the machine men could only with great difficulty be obtained to hole this particular coal, on account of its hardness.

Secondly, that when the seam was worked by hand labour, the proportion of lump coal and slack was as 3 of coal to 1 of slack, whilst with the machine it is 8 of coal to 1 of slack.

Thirdly, that the work is done independent of the men, who cannot be got to work regularly; consequently the production is more certain with the machine.

The actual cost of getting the coal by the machine and by hand labour has been found from the payments made during a period of six weeks at the Platt Lane Colliery to be as follows:—

Hand labour . . .	3*s.* 6½*d.* per ton
Machine	3*s.* 1½*d.* per ton

showing a saving of 5*d.* per ton by the machine. This saving is considered to be absorbed by the expense of compressing the air for the machine, and by interest on outlay, and wear and tear.

The increased value of the produce, in consequence of less slack being made by the machine than by hand labour, is as follows:—

		s.	*d.*	Average Value.
Hand Labour.	3 tons of coal at 11*s.*	33	0	
	1 ton of slack at 7*s.* 3*d.*	7	3	
	Total 4 tons got	40	3	= **10***s.* **0**¾*d.* per ton.
Machine.	8 tons of coal at 11*s.*	88	0	
	1 ton of slack at 7*s.* 3*d.*	7	3	
	Total 9 tons got	95	3	= **10***s.* **7***d.* per ton.

showing an increase of 6¼*d.* per ton in the value of the coal when the machine is employed. In a seam of coal a few inches thicker, and under more favourable circumstances, it is considered there would be a saving over manual labour of from 25 to 30 per cent.

The cost of getting the coal by the machine has been given above as 3*s*. $1\frac{1}{2}$*d*. per ton; but this cannot be taken as a correct representation of the cost by the machine in ordinary cases of working, the machine at the Platt Lane Colliery being the first that was put to work, and for a commencement a liberal rate of pay was given to the collier attending it, as an inducement to give it a fair trial. The same man has now been working it on contract for the last fourteen or fifteen months, and he now earns more than three times as much per day with the machine as previously with the pick.

Mr. E. Fidler said he had now had one of these coal-cutting machines in regular work for nearly two years at the Platt Lane Colliery, and he considered it a very valuable improvement in coal getting, and one that would be particularly opportune at the present time, when there was so much difficulty in obtaining a supply of coal sufficient to meet the demand. The speed at which the machine performed the undercutting depended on the pressure of air supplied; with 30 lbs. pressure per square inch the length undercut in the very hard seam in which the machine was working was 1 yard per minute to the depth of 2 ft. 10 ins. from the face; and with 12 to 15 lbs. pressure more than 6 yards length was undercut to the same depth in 10 minutes, or at the rate of 36 yards per hour. The usual depth of cut with the machine was 2 ft. 9 ins. or 2 ft. 10 ins., and by hand labour with the pick about 2 ft. 8 ins.; and the work done by hand by each collier did not average $4\frac{1}{2}$ yards forwards per day of ten hours; so that the machine performed in eight minutes the same amount of work that one man would do in ten hours with the pick. The machine could safely be relied upon to hole regularly from 80 to 100 yards per turn of ten hours; and as

it was only a question of the length of straight face of coal available for the machine to be employed upon, there was nothing to prevent it from working two turns in the 24 hours, giving 160 to 200 yards of undercutting, or more than could be done by thirty or forty colliers in the day of ten hours. Practically the machine at his colliery had been cutting 72 yards in $4\frac{1}{2}$ hours, or at the rate of 16 yards per hour, including stoppages, as there was not at present a sufficient length of working face open for enabling it to do more; and the estimate of 80 to 100 yards per turn of ten hours was therefore quite within the mark. Under these circumstances the saving in cost of working the machine, as compared with hand labour, had not exceeded 5*d.* per ton of coal, and this he considered was absorbed by the cost of supplying the air and by the repairs of the machine. The great advantages which he had experienced in the use of the machine were, that it was working in a seam of very hard coal, only $2\frac{1}{2}$ feet thick, where it was difficult to get colliers to work at all; that it could be worked either day or night, or both; that a greater weight of coal could be got in the same time from a given extent of working face; and that, in consequence of the much smaller proportion of slack made by the machine, the value of the coal was increased to the extent of 6*d.* per ton. Owing to the thickness of the seam being no more than $2\frac{1}{2}$ feet at the Platt Lane Colliery, he did not consider the machine had been tried there under the best circumstances for deriving the greatest advantage from its use; in a seam of 4 feet thickness he considered the cost of getting the coal would be reduced as much as 30 per cent. by the use of the machine, while the total saving in that case would be greater still, on account of so much larger a proportion of the coal being got whole; in the present seam the coal undercut by the machine came down in unbroken lumps of 10 to 20 yards length.

Mr. C. Cochrane enquired what would be the width on the face of the coal of the wedge-shaped cut that would be excavated in holing with the pick tin he same hard seam in which the machine was working.

Mr. E. Fidler replied that the cut made by hand labour to the same depth from the face of the coal would be about 1 foot wide at

the face, tapering down to a point at the inner extremity; and all the coal cut out of that large opening would be made into slack, instead of only the small quantity of slack from the narrow parallel groove cut by the machine.

Mr. H. Lawrence thought that, while the coal-cutting machine now described had the commercial advantage that it would compare favourably with the cost of hand labour, another highly important consideration was that it would work in some coal which could not be worked by colliers; and on this account it appeared to him sufficiently valuable, irrespective of any saving in cost of labour, in enabling coal to be obtained from seams which would otherwise have to lie unworked. In holing in a soft coal, it occurred to him that there might be a liability of the coal coming down before the machine had travelled far, and so jamming the cutting wheel in the groove; and he asked whether any such occurrence had taken place in the working of the machine. He enquired also whether any injury had been done to the machine by bits of coal getting into the teeth of the driving pinion, or by the cutters getting bent or displaced and catching against the teeth of the pinion. In some other coal-cutting machines the holing was done at the very bottom, level with the rails on which the machine ran; but this appeared not to be the case with the present machine, and he enquired what was the height at which the groove was cut by the machine, and how the bottom coal was got below the cut. The simple mode of drawing back the cutting wheel out of the groove, by the circular movement of the arm on which it was carried, seemed to him certainly very ingenious, and he believed it to be new; the application of the driving power to the circumference of the cutting wheel and the use of cutters fixed in the circumference of the wheel had he believed been adopted also in other instances. From his own experience with coal-cutting machines he had found it was generally the case that a machine which would answer for one mine would not do for another; but in order for a coal-cutting machine to be completely successful, he considered it ought to be universally applicable, so as to suit every class of coal and every variety of circumstances.

Mr. Winstanley replied that the height of the groove cut by the machine was about 7 or 8 inches above the bottom of the seam in the present instance, that height having been found the most convenient; and when the upper coal had been broken down and removed, the coal below the cut was easily got up from the bottom in lumps by means of an ordinary wedge. The height of the cut could be varied by altering the level of the rails on which the machine traversed along the face of the coal; or by modifying the construction of the machine itself, so as to have the cutting wheel at the required level. As the machine traversed forwards in working, wooden wedges were inserted behind it in the groove every 4 or 5 yards, and the coal being very hard these were sufficient to keep it from falling down until their removal on the completion of the holing. It was very seldom that the coal had come down upon the cutting wheel of the machine and jammed it; but such cases had occurred, and were readily met by simply stopping the forward traverse of the machine, and continuing to drive the cutting wheel, while at the same time drawing it backwards out of the coal by the radial arm carrying it, so as to make it cut its own way out of the coal which had fallen upon it; this coal was then either removed or wedged up securely, and the machine put to work afresh. He was not aware of any similar machine in which the driving power was applied in the same way by means of a pinion at the circumference of the cutting wheel; but there were other coal-cutting machines in which a similar cutting wheel was cogged inside the rim, or driven by a bevil pinion gearing into teeth on the top of the rim, the power thus being applied near the circumference, though not actually at the circumference as in the present machine. He had not had any experience of the working of the machine in very soft coal, and thought in such cases a coal-cutting machine was scarcely required; it was wanted particularly for hard coal, difficult to be got by hand labour.

Mr. E. Fidler said, in regard to stoppages, he had found the machine was not stopped so much as once a month by the coal coming down on it. In the event of any of the teeth in the cutting wheel getting loose in working, they simply dropped out without causing any damage to the machine or any stoppage, and were found

again afterwards in the slack when screened. In the first trial of the machine it had been constructed to cut the groove at a height of only 4 inches above the bottom of the seam, but it was then found that the slack and dust thrown out from the groove were inconveniently in the way of the driving pinion, on account of its being so close to the floor, and a scraper had to be fixed on the machine for clearing the road for its progress. Now however that the holing was done at the higher level of 7 or 8 inches above the bottom, the scraper had been dispensed with, and no trouble was experienced from dust getting into the driving pinion. The machine was under the entire charge of a working collier, who had now been working it fifteen months on contract; and no extra allowance had been asked for on account of any difficulties or stoppages, nor had any advance been made in the payment for the work done, except the ordinary rise in colliers' wages.

The President enquired what was the mode of fixing the cutters in the circumference of the cutting wheel.

Mr. F. F. Ommanney, as the maker of the machine, replied that each cutter was secured in its socket by a steel set-screw, which screwed into a wrought-iron nut let into a recess in the cast-iron cutting wheel; the extremity of the set-screw bore against the square shank of the cutter, and thus fixed it securely.

Mr. F. J. Bramwell remarked that, from the mode of actuating the slide-valves of the oscillating cylinders driving the cutting wheel of the machine, by means of levers working in stationary inclined slots, it appeared the full pressure of air would be kept on to the end of the stroke, producing a square indicator diagram without expansion. Although there was no necessity for the utmost economy in a machine of that kind, it did not seem desirable that it should work in so wasteful a manner as must be the case where there was no expansion whatever of the air in the cylinders. He enquired whether any indicator diagrams had been taken to show the actual working of the air cylinders.

Mr. F. F. Ommanney said no indicator diagram had been taken from the machine, on account of the difficulty of fixing an indicator for the purpose on the oscillating cylinders. The curved

inclined slots, in which the ends of the valve-levers were made to work by the lateral movements of the cylinders, were fixed on the upper frame-plate of the machine, and were stationary; but the slide-valves themselves were made with lap sufficient to cut off the air at three-quarters of the stroke, so that the air expanded in the cylinders during the remaining quarter of the stroke, as ascertained by trial with a working template of the valve-motion.

Mr. F. J. Bramwell observed that if this were so the lap of the slide-valve must have also the effect of causing the air to be admitted proportionately (one quarter of the stroke) late in the first portion of the stroke, which would be much more objectionable than keeping the full pressure on to the end of the stroke. In introducing the transmission of power by exhaustion, he remembered the late Mr. John Hague had employed a pair of oscillating cylinders, and had used a valve consisting of a cone cast on one of the trunnions, vibrating in a shell; but with this plan, as with a common slide-valve when worked off a fixed incline, a square indicator figure was necessarily produced. It would be very easy however to obtain moderate expansion in the oscillating cylinders of the coal-cutting machine, by the addition of a simple form of link-motion.

Mr. W. Menelaus said that, having paid considerable attention to the subject of coal-cutting by machinery, and watched carefully the several plans that had been tried, he had not yet found any machine that could compete with colliers' labour under the exceptional circumstances attending the working of the thick veins of coal in South Wales. The holing of the coal constituted there only one tenth of the entire labour in the collieries; and the margin for saving upon this portion of the work was therefore so small, that he had given up as hopeless the introduction of coal-cutting machines in that district. The colliers at present worked only one turn of about eight hours per day of 24 hours; and the coal was all brought down by natural pressure during the interval while the men were absent, the bulk of the coal being obtained with very little holing. If three turns were worked per day, he was not sure that the holing might not be

advantageously done by a machine, even in the thick soft veins of the South Wales collieries; and in such a case he should be very glad to adopt machines for the purpose. In thin veins of hard coal he considered the introduction of coal-cutting machines would be attended with very great advantages, and he hoped they would be generally adopted, and thought every possible endeavour should be made to establish their use. The machine now described appeared to him to be one of the best that had been brought forward for coal-cutting, and he thought the principle of its construction and action was more likely to prove the right one than that of machines designed to work a pick in a manner similar to hand labour. One of the earliest coal-cutting machines that he remembered had been made on the same principle of a circular saw; but in that case the cutting wheel had been literally a circular saw, with fixed teeth, and had consequently proved a failure in actual working; the use of moveable teeth in the cutting wheel of the present machine was an important practical improvement, and this machine appeared to him to have been worked out in a very ingenious way, and seemed one of the most likely to succeed that he had yet met with. Whether the air was worked expansively in the cylinders was a question that should not be overlooked in regard to the economy of any coal-cutting machine; and if the expansion could be obtained without complicating the construction of the machine, it was by all means desirable to have the benefit of it. If however it involved the introduction of cams or eccentrics and ordinary valve-gear, he thought it would be better to waste a portion of the power than to introduce those complications, as he considered the utmost simplicity of construction was an object of such essential importance for the success of a coal-cutting machine; and in working with compressed air it must be borne in mind that the power was cheaply produced at the mouth of the pit, and readily conveyed to the machine. The construction of the machine now described seemed to possess the advantage of simplicity, and he thought this machine was very likely to prove one of the best yet introduced; it had also another advantage in being able to hole its own way into the coal at starting, without requiring any preliminary holing to be done by

hand before it could be got to work. He agreed in considering that the discharge of exhaust air from a coal-cutting machine was hardly capable of producing an appreciable effect upon the ventilation of a colliery, as the quantity of fresh air so discharged was insignificant in comparison with the total quantity passing through the mine.

Mr. E. Fidler remarked that where the holing formed so exceptionally small a proportion as only one tenth of the entire labour in a colliery, the principal difficulty would probably be to employ men enough for filling and hauling the coal when got; in the Lancashire district however the holing constituted as much as one third of the entire work, and any saving that could be effected by the use of a machine for undercutting the coal was therefore of importance. In the case of soft coal his own opinion was that a coal-cutting machine was as much wanted as for hard coal, in order that a greater quantity of round or lump coal might be obtained, without so much slack as was produced in holing by hand labour with the pick. For coking purposes the quantity of slack was immaterial; but for general use the round or lump coal was much more valuable, and at his own colliery the result of employing the machine had been that the clear gain of 6*d.* per ton upon all the coal undercut by the machine had been realised, in consequence of the much smaller proportion of slack made in holing by the machine.

The President observed that descriptions had previously been given to the Institution of plans for coal-cutting by machinery, but not by any machine at all similar to that now described. This appeared to have been attended with important economy in working; and supposing even that the machine work was not cheaper than hand labour, a great advantage would be gained in relieving the men from toilsome labour, which he looked upon as a reproach to the present age of mechanical advancement. Another advantage, which would be fully appreciated, was that a machine did not "strike," and that men could more readily be got to superintend its working than to do the holing of the coal themselves with the pick. It seemed to be generally agreed that in hard coal considerable advantage was derived from the use of coal-cutting machines; and

he was sure they would be adopted also for soft coal, whenever it was found they could be advantageously employed in that case as well as for hard coal. The Members would have an opportunity on the following day of seeing the machine described in the paper at work at the Platt Lane Colliery, through the kindness of Mr. Fidler.

He moved a vote of thanks to Mr. Winstanley for his paper, which was passed.

The following paper, communicated through Colonel Clay, was then read:—

ON THE BUCHHOLZ PROCESS OF DECORTICATING GRAIN, AND MAKING SEMOLINA AND FLOUR BY MEANS OF FLUTED METAL ROLLERS.

By Mr. W. Proctor Baker, of Bristol.

The machinery employed in the process forming the subject of the present paper is designed to accomplish purposes with which even the corn millers of this country are but little acquainted. In order to render clear the operation of the machines, a brief description is desirable of the nature and structure of the grain to be dealt with. The covering or skin of the wheat is composed of three different layers or coats, as shown in the magnified diagrams, Figs. 17 and 18, Plate 65; within these is the true grain, consisting of the central floury body of the corn, the germ or embryo, and two membranes. The central body of the corn is built up of minute flour cells of irregular shapes; and all the other portions of the grain together compose the bran. The three outer coats and the outer of the two membranes are composed principally of ligneous tissue, and constitute 3 to 5 per cent. of the whole grain.

The inner of the two membranes, surrounding the floury body of the grain, contains in its cells the principle named Cerealine, which was discovered some years ago by the French chemist, M. Mège-Mouriès, by whom it has been shown that the good or bad colour, the fineness of texture, and even the flavour of bread, depend upon the absence or presence of cerealine in the flour, and that flour not containing cerealine makes better bread and is more valuable than flour in which it is present. The importance therefore of getting rid of the cerealine is apparent. Practically flour containing cerealine produces bread of a brown colour, and the bread becomes

browner as it becomes stale; while flour free from cerealine produces white bread, which retains its colour unimpaired for any length of time. Cerealine is believed to exist in all parts of the grain, and it varies in colour according to its position in the corn; but the most noxious cerealine is contained in the cells of the innermost membrane, and its dark black character is rendered apparent by mixing bran with white flour; the result in baking is not, as might have been expected, white bread with flakes of bran in it, but a distinctly brown loaf. The flour from the centre of the grain is the finest and best; that obtained from the layers near the membranes is inferior, on account apparently of its containing cerealine. The best system of flour making will accordingly be one which effects a complete separation of the coats of the wheat from the flour cells, and which also in breaking up the grain permits the extraction of the white cerealine supposed to exist among the flour cells. The well known fine flour of France and Hungary, which fetches the highest price of any in the market, owes its fine qualities to its being made on this principle, which is the foundation of the Buchholz process. On the other hand, under the ordinary mode of grinding practised in England, the whole grain is broken and smashed up between the millstones, all the component parts being so completely mixed together that it is impossible to separate them by any subsequent mechanical operation of sifting or sorting.

The object of the Buchholz process is to produce what may be termed "true flour," that is, the substance contained in the central body of the grains of wheat, so extracted from them that it is free from any admixture of the coats, and as free as possible from cerealine, and is in a fine granular state, not crushed to powder by pressure or smashing. In contrast with this pure substance, the flour of commerce is really a fine meal, consisting of a mixture of true flour, bran, and dust; and there are no means in existence by which these various substances can be separated after once they have been mingled together. The object to be attained is therefore to remove so much of the

coats of the grain as can be taken away without risk of injuring or removing any portion of the more valuable substance of the interior. There is no reason why the attempt should be made to strip the coat off the grain by the same process by which the interior portion is reduced to flour, and at the same time at which the reduction is effected. To accomplish the process of decortication numerous plans have been tried, and many different machines invented, some of which have done their work well for a time; but sooner or later the grain operated upon has proved too strong and hard, and the machines, if their work was perfectly done, have always worn out, whatever their construction, or whatever the materials of which they were made.

The Hulling Machine shown in Figs. 1 to 3, Plates 60 and 61, has been invented and constructed by Buchholz to overcome these difficulties; and after considerable experience it has been found to do its work with thorough efficiency, and to stand the test of wear. It consists of a series of revolving cast-iron discs A, fixed on a vertical spindle, making about 350 revolutions per minute, and furnished all round the circumference with thin hard steel blades B, set radially and at right angles to the plane of the disc. These blades, of which there are 12 to 16 per inch, are separated by pasteboard packings a little smaller in width and length than the blades, so that the edges of the latter project, as shown in Figs. 4 and 5, Plate 61. In the course of time the steel blades wear down, so that their edges become level with the pasteboard packings, and these are then cut away in order to expose again the edges of the blades. The discs revolve within a cylindrical casing, which is lined on two opposite sides with steel blades C C, Figs. 1 and 3, similar to those on the discs, a clearance of $\frac{3}{8}$ to $\frac{1}{2}$ inch being left all round the discs; and the casing has open wirework D D in the two intervening portions of the circumference, Fig. 3. Between each revolving disc is a fixed annular disc E, furnished on its upper side with a similar arrangement of steel blades, and

situated just below and above the circle of blades in the two adjacent revolving discs, thus dividing the machine into a series of horizontal compartments. Holes F F are made at intervals in the annular discs, and are closed to any required extent by regulating slides I I.

The grain, fed in through a pipe G in the cover of the machine, Fig. 1, passes down between the edge of the blades B on the first revolving disc and the fixed blades C and E in the casing; and then passes down through the holes F into the next compartment below, and so on through the successive compartments to the bottom. A portion of the skin is removed from the grain by the action of each revolving disc, and the particles cut off escape through the wirework portions D D of the casing, Fig. 3, a constant current of air being made to pass down through the machine for aiding their removal. The regulating slides I closing the holes F in the fixed annular discs, Fig. 3, afford the means of retaining the grain a longer or shorter time under the action of the blades in each compartment of the machine; and brushes formed of plates of sheet india-rubber are inserted in the casing at H H, for pressing the grain close up against the revolving discs. The cleaned grain is delivered at the bottom of the machine into the spouts J J, Fig. 1. The machine being built up of a series of compartments, all precisely the same, its cutting power can at any time be readily increased or diminished according to the nature and quantity of the grain under treatment, by increasing or diminishing the number of the compartments.

In order that the hulling machine may continue in an efficient working condition, it is necessary that the edges of the blades should always be sharp; and such is the hardness of the coat of the wheat grain that the keenness of edge is taken off the steel blades in a few hours; but while the sharpness is being worn off the front cutting edge of the blades, a sharp edge is being set up on the opposite side of the blades, so that it is only necessary to reverse the direction in which the discs rotate in order to bring the sharpened back edges to bear upon the

grain. The machine is supplied with reversing gear K, Fig. 1, and in practice the direction is reversed about every twelve hours, the machine being thus self-sharpening.

The cutting action of the hulling machine is perfectly under control, so that either a large or a small quantity of the skin of the grain can be removed, as desired. It is possible with this machine to remove absolutely all the brown matter from the grain, preserving perfectly the shape of the grain and making no waste of flour. Many other machines are excellent polishers of grain, removing the outer skins to the extent of 1 or 2 per cent. of the whole grain; but as these outer skins are nearly transparent and colourless, the advantage gained is not very great. What is required for real utility is that the inner membrane of the coat of the grain should be cut into, and as much as possible of it be removed. A substantial advantage is gained only by the removal of a considerable quantity of the covering, to the extent of at least 7 per cent. of the whole grain, or more; for the worst and most deleterious of the cerealine is then got rid of. The appearance of the "parings" obtained by the use of this huller shows the utility of removing them from the wheat. They form a dark soft greasy substance; and the presence of any of this, even the most minute portion, in flour, is ruinous to the appearance and quality of bread. It is however a most excellent food for cattle and pigs, and its market value is about the same as that of bran; so that there is scarcely any loss by its removal before grinding the wheat. As it is very important that the wheat should be completely freed from the most minute particles of this noxious dust, before it is ground, the wheat delivered from the huller, with so much of the dust as has not been driven off through the wirework of the casing, is led to a separator covered with wire, to sift out every particle of dust; and it is very useful to expose the stream of wheat to the action of an exhaust fan, to carry away any floating particles.

The hulling machine occupies little room; it requires little attention after it has once been set properly to work, and it

will work for twelve months without requiring repairs; when worn, all that is wanted is a new set of blades, which can be refitted expeditiously and cheaply. The power required to drive the huller varies with the description of the wheat passing through it; about 10 to 12 horse power is required to drive a machine that will decorticate about 4 to 5 quarters of wheat per hour. The whole of this power however is saved in the subsequent grinding process, if the wheat be ground in the decorticated state; for having then been deprived of its hard tough skin, it breaks down far more easily than wheat in the natural state, and a pair of millstones grind a far larger quantity per hour, and require much less power to drive them. The commercial value of the operation of this hulling machine varies with the quality of the wheat used. The worse the wheat, generally speaking, the more is it improved by this process; and the very brown Danube, Banat, and Russian wheats are those upon which the greatest gain accrues, amounting to several shillings per quarter. On the better qualities—American, Baltic, and other red wheats—the advantage is less, amounting to from 1*s.* to 1*s.* 6*d.* per quarter; and with fine white wheats it is least. The superiority in quality of the flour produced is not only in its colour, but also in its smoothness of texture and strength; and the hulling machine is therefore by itself of great value, even in cases where the wheat is ground at once on leaving the huller, without undergoing the further process about to be described.

The hulling machine is not intended to remove the whole of the interior membranes of the grain, for if that were done, the central flour globules would be exposed to the action of the blades, and a portion of the best part of the corn would be cut away and mixed with the worst part. The next object therefore is to separate the central portion of the corn from the remaining membrane; and the most simple way would appear to be to scrape this fine internal portion off the membrane, leaving the cells containing the cerealine undisturbed in the

form of bran. This is exactly what is accomplished in the next stage of the Buchholz process: the grain is ripped open, and the flour cells are torn and scraped away from the bran.

The Semolina Mill, by which these operations are performed, is shown in Figs. 6 to 9, Plates 62 and 63: "semolina" signifying a material which has been half ground. The chief feature of the machine is that its operations are effected by a series of pairs of grooved steel rollers L L, running at differential speeds; these are shown to a larger scale in Figs. 14 and 15, Plate 64. The first pair of rollers, at the top of the mill, does that which has been described as ripping open the grain; and for this purpose the surface of each roller is cut into diamond points, nine to the inch, as shown full size in Figs. 10 and 11, Plate 63. The remaining pairs of rollers are all intended by cutting and scraping to tear away from the bran the interior portions of the grain; and in this operation lies the great merit and novelty of the Buchholz process. These rollers are therefore grooved longitudinally, as shown full size in Figs. 12 and 13; there are eighteen grooves per inch in the upper rollers, and the lower ones are gradually finer grooved, up to twenty-eight per inch.

The best arrangement of this mill is to place the rollers as shown in Figs. 6 and 7, Plate 62, so that the fast rollers of each pair can be driven from central shafts by spur gearing M, the slow roller of each pair being driven through spur wheels by the fast one at exactly one third the speed; and the slow roller in each pair runs at from 100 to 110 revolutions per minute. Under each pair of rollers is an oscillating sieve N, Figs. 7 to 9, to receive the stuff which has passed between the rollers; the semolina and flour scraped off by the rollers pass through the sieve, while the larger bran passes over the tail of the sieve to be further scraped again by the next pair of rollers, and so on through the whole series. The semolina and flour passing through the sieves fall into the troughs P underneath, and are delivered by the spouts R to the traversing screw S at the bottom of the mill, by which they are conveyed away to the dressing or sorting reels. The bran finally discharged

from the tail of the bottom sieve is conveyed away separately by the spout T.

Semolina is produced on the Continent by breaking down wheat between millstones kept at such a distance apart that they cannot reduce the grain to flour at one grinding. The grinding has therefore to be repeated several times before the semolina can be detached from the bran; and then by a laborious process of sifting by hand labour or by ventilation the semolina is separated from the bran. The objection to this plan is, that, while only a small proportion of semolina can be obtained by it, a considerable quantity of flour of very poor quality is unavoidably produced, its inferior quality being due to its being mixed with the very small and fine particles of bran, which have been chipped off in grinding; and these particles of bran contain the most considerable portion of the noxious cerealine. At the same time the pressure necessarily employed in grinding has the effect of crushing some of the flour globules to dust, which is the most certain method of destroying their good qualities for bread making. The millstone is indeed but a blunt instrument, and can do its work, like a blunt knife, only when assisted by considerable pressure.

By the employment of the fluted steel rollers rotating at a considerable velocity and at differential speeds, while fixed at a definite distance apart, the sharp keen edges of the flutes on the fast roller act as a series of cutting blades, while the slow roller holds the material, but at the same time passes it forwards. The crushing action of millstones being thus avoided, a large percentage of semolina is produced, with only a small proportion of flour, the whole of the work being done by sharp cutting edges. The continental system of grinding can be remunerative only in countries where a demand exists for the large quantity of inferior flour produced in the operation of grinding wheat into semolina, and where at the same time a very high price can be obtained for the beautiful flour which the small relative quantity of semolina yields. In making a comparison with the

continental system of grinding, it must be remarked moreover that the only kinds of wheat which yield semolina under the millstones are those of peculiar semi-brittle quality; while tender mellow wheat gives no semolina, as its floury portion is pulverised at once into flour by the rubbing and crushing action of the stones. On the other hand by the Buchholz process, the whole principle being that of using a cutting instead of a crushing action, a large percentage of semolina is obtained from even the most tender native wheat, which would yield no semolina under the millstones.

The bran as discharged from the rollers in this process, at T in Fig. 7, Plate 62, is thick, and by no means merchantable; for it has not been sought to cut away from it the whole of the flour cells next to the membrane, because it is desired to leave the noxious cerealine undisturbed. The bran may be ground through millstones, and the flour obtained from it may be dressed out in the ordinary way; but as would be expected, however finely this flour is dressed, it will nevertheless bake brown, as it is the worst flour the grain contains; and the fact that it is so is the very reason why it should be kept apart by itself. The remaining produce of the semolina mill goes all together into the trunks R R, and consists of semolina large and small in size, the small pieces of bran of the same size as the semolina, and the flour which has been made by the rollers. The quantity of this flour should not exceed about 5 per cent. of the original wheat, and its quality is better than the flour made from similar wheat by ordinary millstones. The whole produce, except the bran, is taken to a silk reel, where the head silks dress out all the flour, and the silks at the tail take out the finest semolina or "sharps".

The remaining larger sizes of semolina and the bran of corresponding size are passed over a silk which sorts them into three sizes, and each of these is then freed from the small bran contained in it by the centrifugal separator shown in Fig. 16, Plate 65. A small horizontal wood disc A on the top of a vertical spindle B is made to revolve at such a speed as

will throw the semolina to the sides C C of a cylindrical case D. The bran being lighter cannot be thrown so far, and thus falls into an inner annular division E E of the case, while the fine dust falls into the centre compartment F; and all are collected separately on a lower floor from the spouts. The speed of the disc A in the separator shown in Fig. 16 varies according to the size of the semolina from 250 to 650 revolutions per minute. The semolina is then fit for the millstones, to which it can be led either mixed, or each sort by itself, the flour being afterwards dressed out.

Where there are no millstones, a roller mill may be used to reduce the semolina to flour, consisting of rollers of the same kind as those used in the semolina mill, but with a much finer grooving. The result is a large percentage of flour of great beauty and bloom, quite different in appearance from anything that can be produced by the ordinary grinding with millstones, however finely such flour may be dressed. In fact, however good may be the dressing, it is impossible by that means to restore to flour the properties it has lost by bad grinding. By the roller process, flour can be made from wheat of poor quality, which cannot be equalled in grinding by millstones even if the finest wheat be used. The roller mill is equally adapted to all kinds of wheats, but the gain is naturally greater with coarse red wheat, containing as this does much brown matter. Many descriptions of red wheat are sound and strong, and have no drawback but the bad colour of the flour they yield under the old plan of grinding by millstones, and they may always be bought at a low price. But with the roller mill, such wheats as some of the Banats, Hungarian, and Black Sea, produce flour which is better and whiter in bread than any that can be obtained by millstones from the best white English wheat. It is found moreover that flour freed from cerealine produces about 10 per cent. more weight of bread than ordinary flour.

In reference to the commercial value of the Buchholz process, the question is whether quality is gained at the expense of quantity, or whether there is any other disadvantage accompanying

the gain. The circumstances of working vary in different districts, but the experience of this plan has definitely shown the profit in working to be from three to four times as great as that under the old millstone system.

A series of samples were exhibited of the grain and semolina from the successive stages of the process, and of the flour produced by mixing together the several qualities of semolina and grinding them by millstones. Specimens were also shown of the blades employed in the huller, for removing the external husk of the grain.

Mr. W. E. Newton observed that the object aimed at in the semolina mill described in the paper appeared to be to produce white flour, by removing from the grain all those portions that would tend to give any colour to the flour; but he feared in this way a portion of the grain was got rid of that was valuable on account of its nutritive properties. It was true that in the Hungarian and French mills the great object was considered to be the production of perfectly white flour, which was of such beautiful appearance; and many contrivances had been adopted for that purpose, including the machine now described. But he thought it was a mistake to imagine there was any advantage in getting rid of the cerealine, except in respect to the colour of the flour produced. It had been mentioned in the paper that the cerealine removed from the flour in this process was used as food for cattle, and was found excellently adapted for that purpose; and it appeared to him therefore that the nutritive properties rendering it a good food for cattle showed it to be suitable as an ingredient of human food. This view was one which had been frequently advocated, and more attention was now being paid to the question of preserving more completely the nutritive properties of food materials in general. If

the Buchholz system had been limited to removing only the outer cuticle of the grain, which contained no nutriment whatever and was also nearly always dirty, a flour would have been produced retaining all the nutritive properties of the grain. Irrespective however of this question, he thought there could be no doubt that the mechanical arrangements which had been described were perfectly successful in effecting the object aimed at.

Mr. F. J. Bramwell considered the huller described in the paper was a great improvement upon that which had been in use so long previously for the same purpose; the use of steel blades, and the fact that these were self-sharpening by the working of the machine, were important practical advantages. A huller employed at Messrs. Gibson and Walker's mills at Leith, where Carr's disintegrating flour mill was in use, was fitted with blades made of common window glass, which he understood were found to work admirably. With regard to the desirability of retaining in the flour all the constituents of the wheat, he thought it might be assumed that in this matter the millers knew their own business best; and whatever were the cause, it was the fact that a higher price was obtained for a beautiful white flour than for one containing the brown specks of alleged nutritive material which it was represented ought not to be rejected. He understood also that the really pure white flour possessed the advantage of making a greater weight of good light bread than could be produced from an equal weight of flour containing the bran particles mixed with it. The Members would have the opportunity of seeing in operation in Liverpool the four modes of producing flour: the Buchholz system at Messrs. Radford's mill, the Hungarian system and Carr's disintegrator at the North Shore Flour Mills, and the ordinary English plan of grinding by millstones.

Mr. S. S. Allin said he was not prepared to agree in the opinion that what was good food for cattle must also be good food for man. The fact that the quality of bread was due to the proportion of cerealine it contained was one to which attention had first been directed by the French chemist, M. Mège-Mouriès, whose experiments had proved that by eliminating the cerealine from the

flour a larger produce of wholesome and more saleable bread was obtained from a given weight of flour; and this result was corroborated by experiments conducted under the direction of the French Government, which showed a gain of 10 per cent. in the weight of bread produced when the cerealine had been got rid of. The loss of nutriment in bread free from cerealine could not be anything very serious, as the total amount of cerealine in wheat grain was only about 4 per cent., of which about 2 per cent. was in the bran or husk, and the remaining 2 per cent. was distributed amongst the little cells of the kernel. About one fourth of the cerealine was removed in the bran in the ordinary process of grinding, and the object of the Buchholz system was to remove as much as possible of the remaining 3 per cent. It was not practicable to remove this thoroughly if the grain was ground down into flour at once; and it was therefore done by breaking down the grain more gradually, into semolina of successive degrees of fineness, and liberating at each stage as much as possible of the cerealine; the latter was then separated from the clean semolina by the centrifugal separator, the cerealine being not thrown to so great a distance from the separator on account of its greater lightness. The removal of the cerealine from the flour was desirable on account of its chemical characteristics, which were very peculiar. It was one of the most active ferments, generating ammoniacal salts, and having besides a tendency to rot the fibre of the gluten in the flour. As the lightness of bread depended upon the elasticity of the gluten cells and their consequent capability of expanding under the action of the carbonic acid gas which was generated in the process of fermentation, the presence of cerealine by rotting the fibre of the gluten cells caused them to collapse instead of expanding in the fermentation, and thus rendered the bread heavy, close, and indigestible; but when the cerealine was eliminated from the flour, the gluten cells retained their elasticity, and the result was a light porous bread which sold better than any bread made from flour containing cerealine. There was the greatest proportion of cerealine in rye, and it was this which caused the flour of rye to make black bread. The more completely the cerealine was eliminated from any

flour, the greater was found to be the weight of bread that could be made from the flour, and the higher the price it would obtain.

The President enquired how long the Buchholz system had been in use, and how many mills were working on that plan, and at what places it had been already adopted in this country.

Mr. S. S. Allin replied that the plan had already been in use about two years in this country, and was now in operation at Messrs. Baker's mills in Bristol, Messrs. Radford's in Liverpool, Messrs. Stannard's at Colchester, and he was himself introducing it in Ireland at Cork, Midleton, and other places. In Hanover it was now being adopted on a large scale by an association of millers. Many improvements had been introduced in the later machines, but those put up in the earlier stages of the invention still continued at work, and were as efficient in respect to the result produced as the machines constructed more recently.

Mr. F. J. Bramwell enquired what quantity of wheat per week could be treated by one of the roller mills with huller, and what was the power required to do the work.

Mr. S. S. Allin replied that one of the semolina mills with huller was capable of converting into semolina 1000 quarters of wheat per week (8000 bushels). The total power required was about the same as in grinding the same quantity of grain by millstones, more power being expended in cleaning or decorticating the grain in the Buchholz system, and less in the subsequent grinding of the semolina into flour; while the flour so produced was invariably of better quality and more valuable than that obtained from millstones in the ordinary mode of grinding.

Mr. R. Mallet remarked that the removal of the cerealine from the flour was a question of profit with the millers and bakers, but with the consumers of the bread the question was not merely one of the quantity of bread obtained for a given sum, but rather what amount of nutriment was contained in it. The cerealine contained not only most of the oily part of the grain, which formed an important part of the heat-producing principle in the bread, but also, as was evident by its ready fermentation, the nitrogenous particles, which went to the formation of flesh; and he thought therefore the removal

of the 4 per cent. of cerealine, though resulting in the production of flour of beautiful appearance, might be undesirable as possibly depriving the bread of an important amount of its nutriment. In illustration of the value of the oily and nitrogenous matters in grain, it might be mentioned that in the great pork-fattening district of Cincinnati the food preferred for the purpose was almost exclusively a variety of brown indian corn, which was indeed almost black and contained the largest percentage of oily and nitrogenous matters analogous to those in cerealine; and anatomical considerations led to the conclusion that the same nutritious ingredients were equally desirable in human food.

Mr. W. E. Newton fully admitted that flour in which the cerealine was retained made close bread, instead of the fine porous bread produced from beautiful white flour; but chemical and physiological investigations had shown that bread made from the finest white flour was the least digestible, while on the other hand it had been proved that the close bread containing the cerealine was more digestible and nutritious than bread made from the fine white flour, the appearance of which had been so highly spoken of.

The President thought the two opposite opinions expressed with regard to the removal of the cerealine from the flour for making bread might be reconciled by the consideration that the grain upon which animals were fed constituted their entire food, and they received no other nitrogenous substances, such as those supplied in human food from animal sources. There could be no doubt that in removing these nitrogenous substances, cerealine especially, from the flour, a good deal of the nutriment of the flour was thrown away; but whether this was balanced by other advantages—whether the bread being more light and porous was more suitable for mixing with animal food—was a question which was not easily answered, and which he thought might be left to the larger experience of those who had specially studied the subject.

He proposed a vote of thanks to Mr. Baker for his paper, which was passed.

The PRESIDENT moved a vote of thanks to the Mayor and Corporation of Liverpool, for their kindness in granting the free use of the Rooms in St. George's Hall for the purpose of the present Meeting of the Institution; to the Local Committee, and the Chairman, Colonel Clay, and the Honorary Local Secretary, Mr. Daniel R. Ratcliff, for their active exertions in promoting the success of the Meeting, and the very excellent arrangements made for the occasion. He also moved a vote of thanks to the Proprietors of the various Works so liberally thrown open to the Members during the Meeting; and to the London and North Western Railway Company for the important facilities so kindly granted to the Members for the Excursions, enabling them to visit the different Works opened to them.

These votes having been passed, the Meeting then terminated.

In the afternoon the Members visited Messrs. Laird's Shipbuilding and Engine Works, Birkenhead, where nearly 3000 men are employed. Five ships were seen in process of building, three of 3400 tons each, and two of 2200 tons. Two ships, the "Greece" and the "John Elder," were being lengthened 60 feet and 26 feet respectively, increasing their tonnage 700 and 300 tons, making a total of about 4300 and 4100 tons; and a very light steamer of only 2 feet draught was being constructed of steel, for use on one of the shallow western rivers of South America. Three pairs of compound marine engines of 600 horse power and two pairs of 400 horse power were seen in course of construction, and one pair of 450 horse power completed in the "Greece." These engines contain all the newest arrangements for ensuring economy and convenience of working; and among other things was observed an easy mode of access to the foot-valves of the air-pumps, by the introduction of a manhole in one side of the working barrel of the pump; the manhole cover is fitted in its place, and the air-pump

barrel is then bored out with the cover in position. The shops contain a number of heavy engineering tools for planing and boring the large and complex engine castings; and special facilities are provided for conveniently handling these heavy masses. By the side of one of the docks, which can be used either as a floating dock or as a graving dock, is a large crane worked by steam power, capable of lifting 50 tons; and by this the engines and boilers made in the works are put into the ships after they are launched, while the masting and outfit are being otherwise completed, so that the ships may leave the works practically ready for sea.

The Members were then conveyed by a special steamer, through the kindness of Mr. Charles Mac Iver, to visit the large Atlantic steamship "Scotia," lying in the Mersey. This is the last of the Cunard Co.'s paddle-wheel ocean steamers, and has a pair of single-cylinder engines of 100 inches diameter and 12 feet stroke, constructed by Messrs. Robert Napier and Sons; they are side-lever engines, the side levers being each formed of two solid wrought-iron plates bolted together; and the engine frames are an excellent combination of wrought and cast iron, giving great strength.

In the evening the Members were entertained at Dinner in St. George's Hall, by invitation of the Liverpool Engineers and Shipbuilders and Steam Ship Companies.

On Tuesday and Wednesday afternoons the following Engineering Works and Manufactories &c. were opened to the visit of the Members:—

Messrs. Fawcett Preston and Co., Phœnix Foundry.
Messrs. George Forrester and Co., Vauxhall Foundry.
Messrs. James Jack, Rollo, and Co., Victoria Engine Works.
The Mersey Steel and Iron Works.
Messrs. Thomas Milner and Son, Phœnix Safe Works.
Messrs. Francis Morton and Co., Galvanised Iron Works.
Messrs. Walker Campbell and Co., Tinned Lead Pipe Manufactory.
Messrs. Radford's Flour Mills. Buchholz system of decorticating grain, and making semolina and flour by means of fluted metal rollers.
North Shore Flour and Rice Mills. Hungarian system of grinding. Carr's disintegrating flour mill.
Ventilating Fan of Lime Street Railway Tunnel, Smithdown Lane.

Liverpool Water Works. Audley Street Pumping Engine and Reservoir; Windsor Pumping Engine; Kensington Reservoir.
Liverpool Gas Works.
Chain-Cable Testing Works.
Grain Warehouses. Hydraulic grain-traversing machinery.
Messrs. Earles and King, Seed Crushing Works.
Messrs. A. M. Smith and Co., Seed Crushing Works.
Messrs. Cope Brothers, Cigar Manufactory.
Ocean Steamers of the Liverpool Steam Ship Companies.
The Bidston Observatory, Birkenhead.

On Thursday, 1st August, an Excursion was made by the Members by special train from Liverpool to visit several Collieries and Iron Works &c. in the neighbourhood of Wigan.

The Pemberton Colliery of Messrs. J. Blundell and Son was first visited. At the working shaft, which is 640 yards deep and 17 feet diameter, the heapstead is constructed entirely of iron, the staging being carried on lattice girders supported by cast-iron columns with lattice bracing, the whole forming a very durable and stiff framework. The cages each hold six tubs, and have three decks; the ropes, cages, and tubs are all made of steel. The large conical winding drum is 30 ft. 6 ins. diameter, and weighs with the shaft about 49 tons; it is arranged for winding from the depth of 630 yards in $21\frac{3}{4}$ revolutions, the time occupied being 48 seconds, which gives an average speed of about 26 miles per hour in the shaft; the drum is driven by a pair of horizontal engines, with cylinders 36 inches diameter and 6 feet stroke, and Cornish valves. The pulleys over the pit mouth are 18 feet diameter. The large Guibal ventilating fan is 46 feet diameter and 15 feet wide, constructed of steel, and driven by a horizontal engine with 36 inch cylinder and 3 ft. 6 ins. stroke, a duplicate engine being provided to meet any emergency. The fan is running at present at only about 38 revolutions per minute, giving a vacuum of 2·45 inches water gauge and a current of 155,600 cubic feet of air per minute; but when in full work it is intended to run at

50 revolutions, at which speed it is calculated to give 230,000 cubic feet per minute. Some of the boilers supplying steam to the winding engines and fan engine are fitted with mechanical firegrates, some on Vicars' and the rest on Taylor's plan, the latter being a modification of Juckes' grate (see Proceedings Inst. M. E. 1869 page 155).

The Members next visited Messrs. Rylands and Sons' Cotton Mill, recently erected and furnished with the latest improvements in the machinery for spinning and weaving cotton. The weaving shed contains 1158 looms, all of the same pattern, and the driving belts are led off horizontally on both sides of the main lines of shafting, and pass down over guide pulleys to the looms; the strains thrown upon each line of shafting by the pull of the belts are thus equalised, and the friction consequently reduced. The mill is driven by two pairs of single-cylinder horizontal engines, with cylinders 40 inches diameter and 6 feet stroke.

The Wigan Coal and Iron Co.'s Works were then visited. There are ten blast furnaces, five of which are 80 feet high and 24 feet diameter at the boshes, and five are 65 feet high and 18 feet diameter. They are all closed at the top with a bell and charging hopper, and the gas is taken off for the boilers and hot-blast stoves. The weekly make of each of the larger furnaces is about 350 tons, and of the smaller about 300 tons; the ore smelted is principally red hæmatite from the Ulverstone district, with a proportion of aluminous ore from the neighbourhood of Belfast. The blast is supplied by three compound-cylinder blowing engines, each of which is an inverted beam engine with the high-pressure cylinder of 45 inches diameter at one end of the beam and the low-pressure cylinder of 66 inches diameter at the other end. Above each steam cylinder is a blowing cylinder of 100 inches diameter, the same piston rod passing through both. No flywheels are used to control the engines, and the stroke is about $11\frac{1}{2}$ feet, the speed being about $10\frac{1}{2}$ to 12 double strokes per minute; the steam valves are worked by tappet gear. An auxiliary blowing engine is

provided, of vertical direct-acting type, having a 35 inch steam cylinder and 70 inch blowing cylinder, with 4 feet stroke. A large chimney 350 feet high and $13\frac{1}{2}$ feet internal diameter is erected for producing the required draught in the boilers heated by the blast-furnace gas. Extensive coal-washing machinery is employed for purifying from sulphur the slack which is made into coke for use at the ironworks.

The Members then proceeded to the Rosebridge Colliery of Mr. J. G. Morris, where they descended the shaft of 815 yards depth and 16 feet diameter, the deepest shaft at present in England. The time occupied by the cage in traversing this depth is not quite one minute, giving a mean speed of about 30 miles per hour in the shaft. The winding drum of 26 feet diameter and 40 tons weight is worked by a pair of horizontal engines with cylinders of 36 inches diameter and 6 feet stroke.

At the Platt Lane Colliery of the Wigan and Whiston Coal Co. the working was shown of Messrs. Winstanley and Barker's Coal Cutting Machine described at the meeting. The machine was seen in operation in the hard seam of coal known as the "Pemberton Little Coal," of only about 2 feet 4 inches thickness, in which it has now been at work daily or nightly for the last two years. The compressed air by which it is driven is supplied by an engine at the pit mouth, having 16 inch steam cylinder with 36 inch stroke and air-compressing cylinder of the same size, compressing about 200 cubic feet of air per minute from atmospheric pressure to 40 lbs. per square inch above atmosphere.

The Ince Hall Coal and Cannel Co.'s Works were then visited. At this colliery the system of hauling the coal tubs by endless chains is extensively carried out, along tramways both on the ground level and raised on timber staging. By this means, with the expenditure of only a small amount of power, all the produce from the several pits is concentrated at one place, and there screened and sorted. The hauling chain simply rests on the top of the tubs, its weight giving hold enough for hauling them; and when not resting on the tubs, it is supported

clear off the ground by cast-iron rollers. The endless chain working each section of tramway passes round a horizontal drum at each end of the section, one of these drums being the driving drum. The system of underground haulage by means of compressed-air engines is extensively carried out in the pits.

The Ince Hall Rolling Mills Co.'s Works were also visited. They have been recently erected, and contain a forge train of 20 inches diameter, with two finishing trains of 16 and 9 inches diameter; the forge train and 16 inch mill are driven direct from the flywheel shafts by two independent horizontal engines, with cylinders 26 inches diameter and 4 and 3 feet strokes respectively; the 9 inch mill is driven from the second motion shaft by an independent horizontal engine with cylinder 22 inches diameter and 2 ft. 6 ins. stroke.

The Members were entertained at luncheon at Wigan by the Wigan Coal and Iron Co., refreshments having also been kindly provided at the several works visited; and they returned to Liverpool in the evening by special train.

The engine drawing the special train throughout the excursion was worked on Warsop's plan of injecting a continuous supply of heated air into the bottom of the boiler, for the purpose of preventing the formation of incrustation, and for increasing the evaporating power of the boiler by promoting a more active circulation of the water (see Proceedings Inst. M. E. 1870 page 229). The locomotive was a six-coupled goods engine that had been running several months with the aero-steam boiler, the air being supplied by a single-acting pump of 6 inches diameter and 2 feet stroke, worked from one of the main crossheads. Before entering the boiler the air is driven through a coil of 1½ inch lap-welded wrought-iron pipe, 61 feet long, arranged in the smokebox, and is then injected into the water through a perforated pipe lying inside the bottom of the boiler.

On Friday, 2nd August, an Excursion was made by the Members by special train from Liverpool to Runcorn and Crewe.

The works of the Widnes Metal Co. were first visited, where was seen the extraction of copper by the wet process and of silver by Claudet's process from the refuse burnt pyrites supplied from sulphuric acid works. The pyrites (bisulphide of iron) consists originally of nearly 47 per cent. of iron and 53 per cent. of sulphur, with minute proportions of copper and silver in the state of sulphides; but the burnt pyrites, from which most of the sulphur has been extracted for making sulphuric acid, retains only about $3\frac{1}{2}$ per cent. of sulphur, while the proportion of copper is increased to about 4 per cent.; about 12 dwts. of silver are contained in each ton of burnt ore. The burnt pyrites, having first been crushed fine between rollers, is mixed with common salt (chloride of sodium), and the mixture is roasted in reverberatory gas furnaces, whereby part of the salt is converted into sulphate of soda, and the insoluble sulphides of copper and silver into chlorides, which are soluble in brine. The roasted mass is then exposed to successive washings in a series of large wood tanks; the first three washings serve to carry off the chloride of silver, and after the separation of the silver, these liquors, together with those from the further washings, are run into a tank containing a quantity of wrought-iron scrap, upon which the copper is precipitated from the solution by decomposition of the chloride. The rest of the solid matter left in the tanks, after the precipitation of the copper, is known as "purple ore," and consists mainly of peroxide of iron, containing from 60 to 70 per cent. of iron, and in this state is used as "bull-dog" for the lining of puddling furnaces. The liquors drawn off from the first three washing tanks contain the chloride of silver in solution, and by the addition of soluble iodide of zinc the silver is precipitated as an insoluble iodide; this is afterwards treated with metallic zinc, which decomposes the iodide of silver, liberating the silver, and forming soluble iodide of zinc, ready to be used again for precipitating further quantities of silver from the chloride solution. Salt cake (sulphate of soda) is also recovered from the liquors by subsequent treatment.

The Members next visited the Widnes Soap Works of Messrs. Gossage and Sons. In the manufacture of soap, a weak solution of caustic soda, called "lye," is boiled in a large wrought-iron pan, with the addition of a certain proportion of fatty matter, such as tallow, or palm or cocoa-nut oil; and resin is added for yellow soap. The boiling is effected by blowing steam into the bottom of the pan, and the mixture is treated with successive additions of stronger lye, undérgoing between each a thorough boiling, until the fatty matter has taken up all the soda possible and has thus become completely converted into soap; the excess of lye settles at the bottom of the pan, and is drawn off. The charge of soap is then drawn off from the pan without hand labour, by means of air pressure; the top of the pan is closed by a cover, the joint being made air-tight by an india-rubber packing ring, and compressed air is forced into the top of the pan by a pump, whereby the entire liquid mass of soap, amounting to as much as 20 tons, is expelled from the pan, being forced up through a discharge pipe passing through the cover, and flows through a long trough into the moulds. These are 45 inches long, 15 inches wide, and 52 inches high, each containing about half a ton of soap, and are made simply of four cast-iron side-plates secured by clamps; the soap takes three days to cool and solidify, and the sides of the mould being then removed, the large block of soap is cut horizontally into slabs, which again are divided into bars by a wire frame. The bars of the finer qualities are cut into cakes, which are stamped in a press having a heavy falling die lifted by a cam. The lye, or solution of caustic soda, is concentrated to the required strength for the soapboiling pan by waste heat of the soda furnaces. The manufacture of "silicated soap" was seen, in which a solution of silicate of soda is employed in place of a portion of the tallow or oil used in the soapboiling pans, thus producing a much cheaper soap with equal cleansing power. As ordinary soap owes its cleansing power to the fact that the soda, which constitutes the real detergent, is only in a state of weak combination with the tallow or other fatty substance, the latter can be to a considerable extent replaced by silicate of soda, in which soda exists only in

weak combination with silica, thereby retaining its cleansing power, as in ordinary soap. The silicate of soda, known as "soluble glass," is made by melting in a reverberatory furnace a mixture of fine white sand (silica) and soda ash (dry carbonate of soda); the melted charge is run out through a tap-hole, and solidifies in lumps of a kind of glass, which is soluble in water.

The Alkali Works of Messrs. John Hutchinson and Co. were then visited, and the various processes connected with the manufacture of sulphuric acid and soda were seen. In making sulphuric acid, iron pyrites (bisulphide of iron) is burnt in kilns, and the sulphur being driven off in the form of sulphurous acid gas is conducted into large leaden chambers, 30 to 70 feet square and 20 to 25 feet high, along with air, steam, and nitric acid vapours, by which the sulphurous acid is oxidised; the floor of the chamber being covered with a few inches depth of water, the resulting sulphuric acid is condensed and collected in the water, and the dilute acid flows off continuously through the lute joint all round the bottom of the leaden chamber. This acid is employed without concentration for the manufacture of sulphate of soda, by mixing it in shallow cast-iron pans with common salt (chloride of sodium) from the Cheshire salt mines; hydrochloric acid gas is evolved under a moderate heat, and the residue being afterwards roasted in a reverberatory furnace till nearly free from acid, becomes "salt cake" (sulphate of soda). The hydrochloric acid gas driven off, which was formerly wasted by being discharged into the atmosphere, is now almost entirely saved by being made to pass upwards through a tower containing a mass of open brickwork or coke, through which a slight shower of water is kept constantly falling; the gas is absorbed by the water, and the acid thus formed is collected at the bottom of the tower. The salt cake (sulphate of soda) being roasted with small coal and limestone by Leblanc's process in a revolving furnace, these materials are converted into carbonate of soda and sulphide of calcium, the mixed product in this state being known as "black ash." Hand furnaces are also used, and in some of these the mass is stirred during the roasting by Dormoy's

rotary rabble; and when thoroughly converted the melted mass is drawn out, cooled, broken up, and placed in lixiviating vats, where the carbonate of soda is dissolved out of the black ash by water, leaving insoluble "waste." The solution of carbonate of soda, called "vat liquor," is treated either by causticising or by salting-down. In causticising, the vat liquor is boiled by steam with caustic lime, whereby the carbonate of soda loses its carbonic acid and is converted into hydrate, the solution of which, after being concentrated in pans, is supplied for soapmaking and other manufactures; it is also further boiled down in iron pans till nearly red hot, and on cooling, the solid caustic soda is either packed in iron drums or run on to plates to be broken up. In salting-down, the vat liquor is boiled down by waste heat from the black-ash furnaces, till converted into a mass of grey crystals called "salts," which is calcined in a reverberatory furnace till quite white, when it is called "soda ash;" this is carbonate of soda, and is again dissolved in hot water, and the solution being allowed to settle and crystallise in iron pans forms hydrated crystals of carbonate of soda, the "soda" used for ordinary domestic purposes. Bicarbonate of soda, from which effervescent liquors are made, is produced by placing the soda crystals in iron chambers, through which carbonic acid gas, generated by the action of hydrochloric acid on limestone (carbonate of lime), is passed for several days, driving out the water of crystallisation, and adding a second equivalent of carbonic acid to the carbonate of soda; the bicarbonate is gently dried in kilns and ground in a mill. The insoluble black mud or "waste" left in the lixiviating vat, consisting mainly of sulphide of calcium, was formerly altogether thrown away and wasted, but is now utilised for the manufacture of sulphur by Mond's process. For this purpose air is blown through it while still in the vat, to oxidise a portion of it into soluble hyposulphite &c., which is then lixiviated with water, and the solution mixed with hydrochloric acid; pure sulphur is thereby precipitated, which is washed, melted by superheated steam, and run into moulds. Bleaching powder is manufactured by Deacon's process; hydrochloric acid gas is

decomposed by being passed over sulphate of copper heated to 800° or 900° Fahr., and the resulting chlorine gas after being washed and dried is passed into slate chambers containing slaked lime; hypochlorite of lime is thus produced, which forms the bleaching powder, evolving free chlorine when moistened with water.

The Members proceeded from Widnes to the Runcorn Railway Bridge over the Mersey, which is constructed of lattice girders in three spans of 305 feet each in the clear, with 75 feet clear headway above high water level. The depth of the girders is 28 feet, and the top and bottom flanges are 5 feet wide and of box construction; the floor of the bridge is wholly of wrought iron. The deflection in the centre of each girder, when tested with sixteen of the heaviest locomotives on one span, did not exceed 1 inch. The river piers are of masonry and brickwork, resting on the red sandstone rock; the foundations extend to a depth of 45 feet below high water, and were put in by means of cast-iron cofferdams.

The Crewe Locomotive and Steel Works were then visited by special train. In the extensive shops of the locomotive works a large number of engines were seen in all stages of construction and repair. In the boiler shop the testing was witnessed of samples from the Bessemer steel plates, $\frac{3}{8}$ inch thick, now being adopted for the locomotive boiler shells; these plates are required to have a tensile breaking strain of 34 tons per square inch, and to stand an elongation of 25 per cent. before breaking, and a $\frac{5}{8}$ inch hole punched in a sample strip of 3 inches width, cut from each plate, is required to stand drifting out to 2 inches diameter without the metal cracking. In the extensive Bessemer steel works the process of tyre-making, the duplex hammers, and the reversing rolling mills, described at previous meetings of the Institution, were seen in operation. The Members were entertained at luncheon at Crewe by Mr. Webb, the Locomotive Superintendent of the London and North Western Railway; and the special train returned to Liverpool in the evening.

On Saturday, 3rd August, several of the Members visited the Marston Hall Rock Salt Mines and White Salt Works, near Northwich, belonging to Mr. William Hayes. The bed of rock salt worked at these mines is situated at a depth of 110 yards from the surface, and has a thickness of about 50 yards, of which only the best portion of about 7 yards thickness is now being worked, the workings having been commenced in 1851. The roof of the workings is supported by pillars about 10 yards square at intervals of 30 yards; the extensive caverns thus formed were well displayed by the burning of coloured fire for their illumination on the occasion. There is no water to contend with, and no provision for ventilation except the two drawing shafts about 4 feet diameter and 15 yards apart, either of which serves as downcast or upcast, according to chance. The bottoms of the shafts open in the roof of the workings, no shaft pillar being left round the bottom of either shaft. The working faces are pushed forwards in two banks, the upper one, of about 3 yards height, being carried a few yards in advance of the lower bank, which is worked as a quarry by blasting. The upper working face is undercut, and broken down with powder, and Walker's rotary cutting machine is employed for the undercutting, having a horizontal wheel $4\frac{1}{2}$ feet diameter, which carries a set of cutters fixed round its circumference, and gears by bevil teeth on its upper face with a driving pinion upon the crank shaft of a pair of horizontal cylinders worked by compressed air at a pressure of about 40 lbs. per square inch; as the cutting progresses, the machine is hauled along the face of the rock by a winch worked by manual labour. The groove is cut to a depth of about 27 inches in from the face and is about 3 inches wide, and the rate of advance of the machine is from 8 to 10 yards per hour. The greater part of the rock salt is shipped to Holland and Belgium, where it is dissolved to form brine from which common white salt is obtained by evaporation. The rest is crushed fine between rollers and riddled, and is supplied partly for the copper and alkali works, but mainly for agricultural purposes, for which, owing to its containing 7 per cent. less impurities than common white salt obtained by evaporation,

and these impurities being also of use as valuable fertilisers, it is gradually superseding the use of common salt; the latter takes $\frac{1}{2}$ ton of coal to produce 1 ton of salt by evaporation, and consequently costs about 6*s*. per ton more than the screened rock salt. At these works was also seen brine pumped from natural springs by shafts 75 yards deep; the brine is run into shallow evaporating pans, and white salt is deposited by evaporation.

EJECTOR CONDENSER.

Fig. 1.

End Elevation of Engine
with Ejector Condenser.

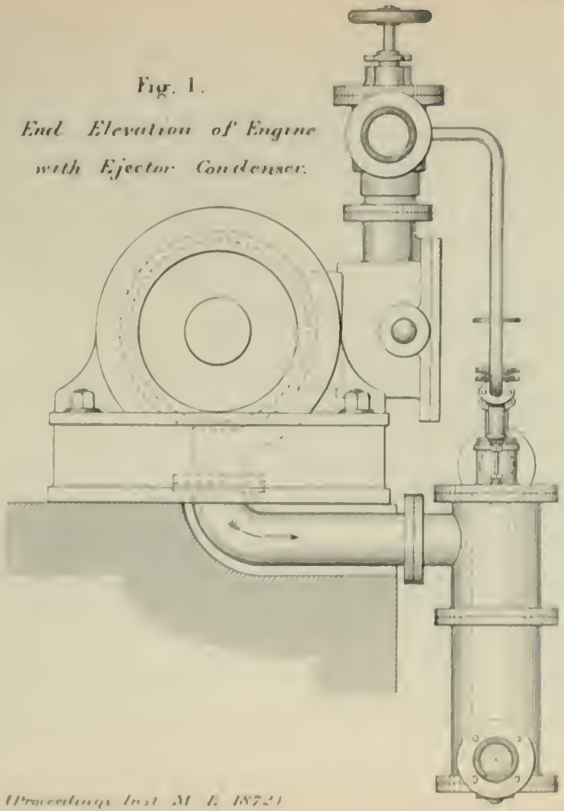


Fig 2

Side Elevation of Engine
with Ejector Condenser

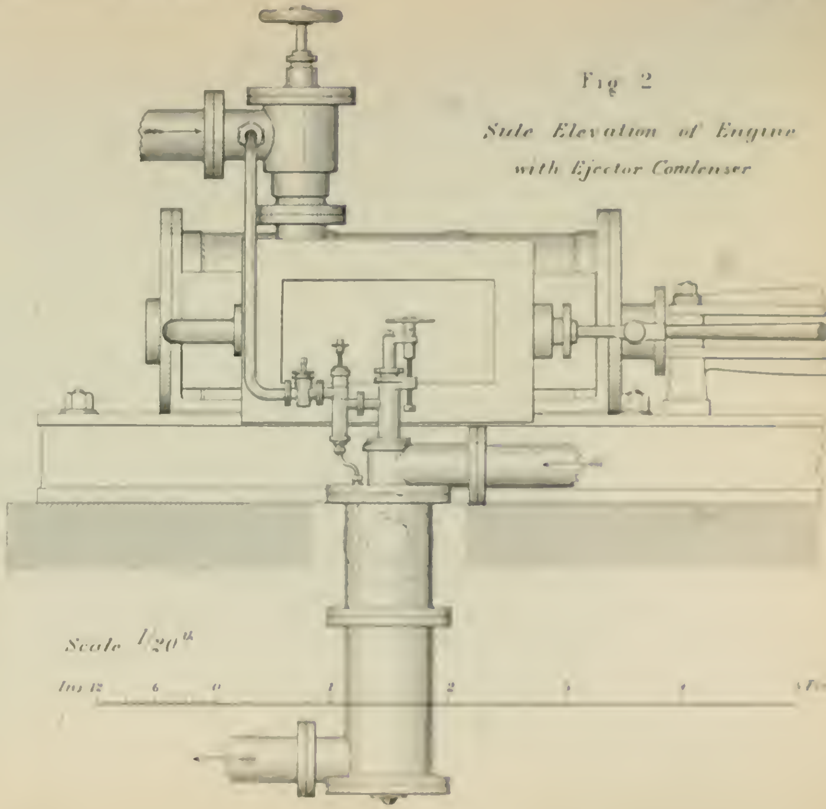


Fig 3. *Condenser supplied with head of injection water*

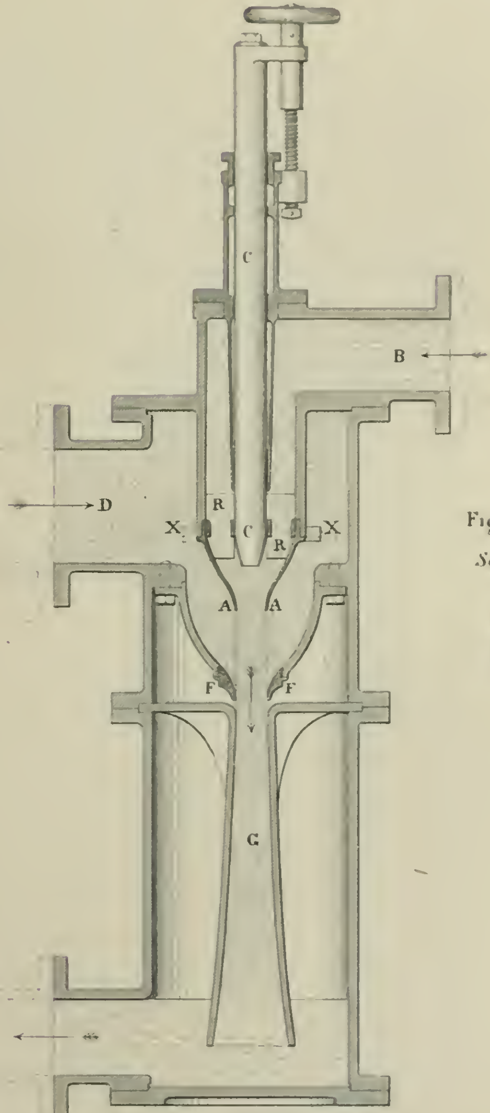
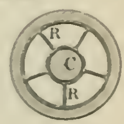


Fig 4 *Transverse Section at XX*

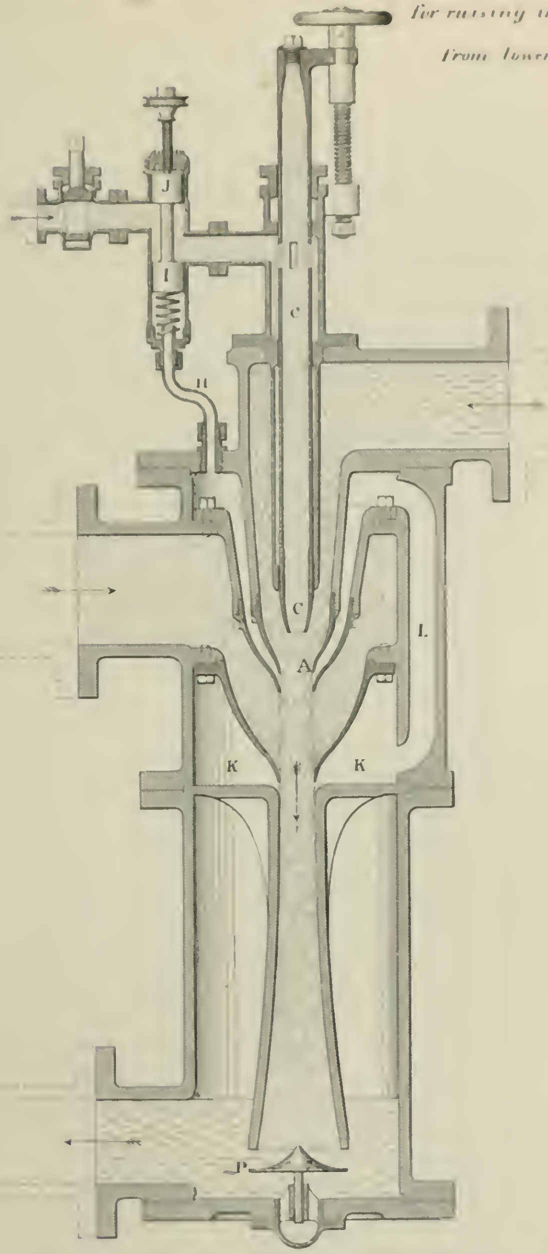


(Proceedings Inst M E. 1872)

Scale 1/12th

0 5 10 20 30 40 Inches.

Fig. 5 Condenser with self-adjusting Jet of Boiler Steam for raising injection water from lower level

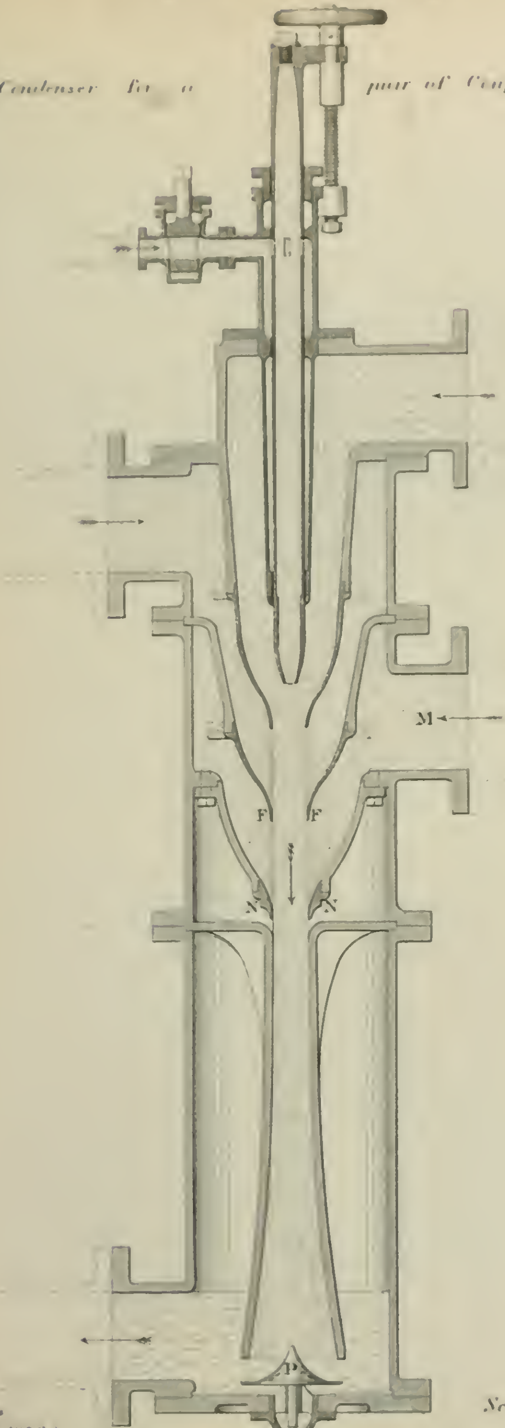


(Proceedings Inst M E 1872)

Scale 1/8th

0 5 10 15 20 25 30 Ins

Fig. 6 Condenser for a pair of Coupled Engines



Scale 1/12th

(Proceedings
Inst. M. E. 1872.)

Fig. 7. *Indicator Diagrams from Pumping Engine at Eyesholm Colliery, Ayrshire.*

Cylinder 18 *ins diam.,* 4½ *feet stroke,* 22 *revs per min.*

Mean effective pressures 16·2 *lbs. Indicated horse power* 24

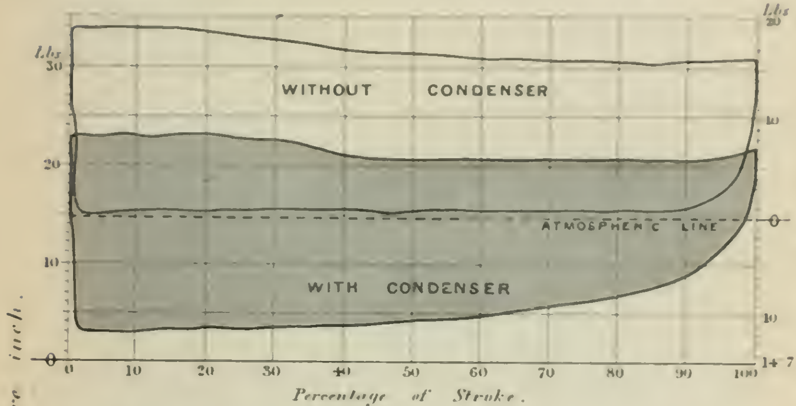
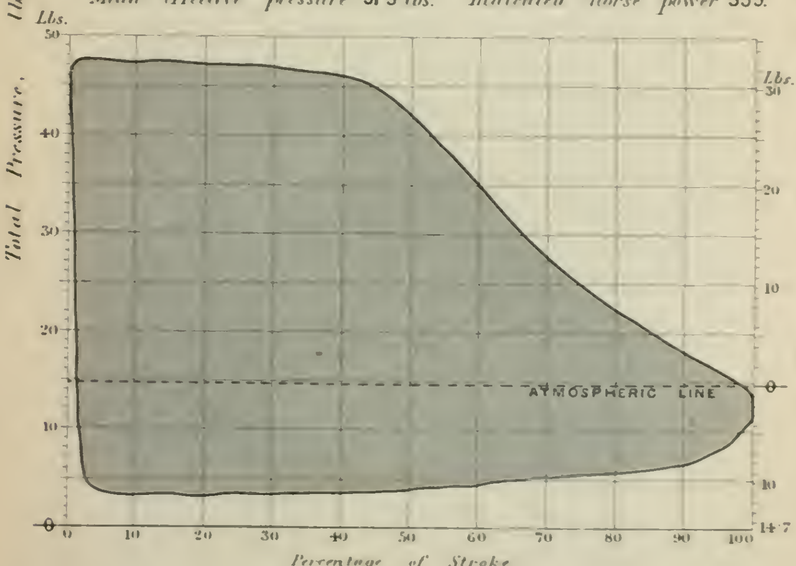


Fig. 8. *Indicator Diagram from Blowing Engine at Llynvi Iron Works, Glamorganshire.*

Cylinder 40 *ins. diam.,* 10 *feet stroke,* 15 *revs. per min.*

Mean effective pressure 31·5 *lbs. Indicated horse power* 359.



Indicator Diagrams from Engines at Albert Works, Glasgow

Fig. 9. *Pair of Cylinders* 10¼ *inches diam* 18 *inches stroke*

110 *revolutions per minute*

Mean effective pressures 21·3 *lbs and* 16·5 *lbs*

Indicated horse power 17½ *and* 13½ *Total* 31.

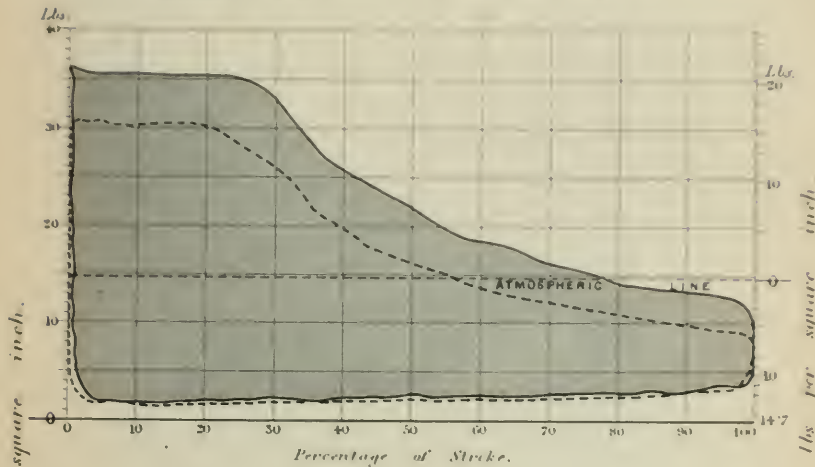
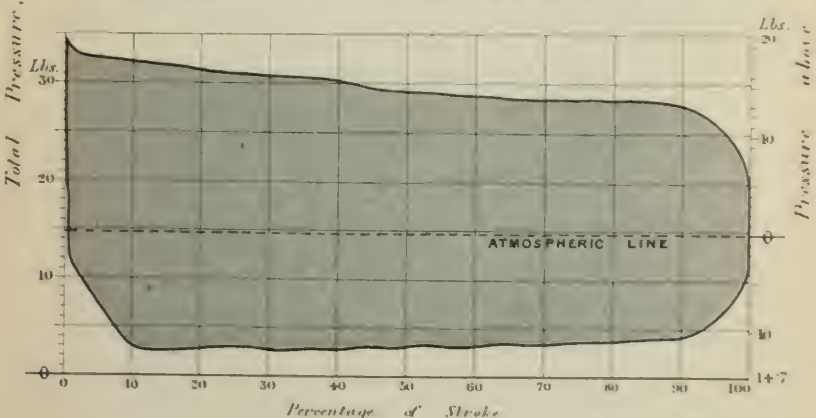


Fig. 10. *Single Cylinder* 8 *inches diam.,* 12 *inches stroke,*

200 *revolutions per minute.*

Mean effective pressure 25·8 *lbs Indicated horse power* 15.



(Proceedings Inst. M. E. 1872.)

Fig. 1. *Indicator Diagrams from Steam Cylinders.*
One pair of cylinders, working two opposite cranks.

24	*revs per min*	$4\frac{1}{2}$	*feet stroke.*
32	*and*	60	*ins. diam. cylinders.*
30·0	,,	7·1	*lbs. mean pressure.*
158	,,	132	*H. P. Total* 290.

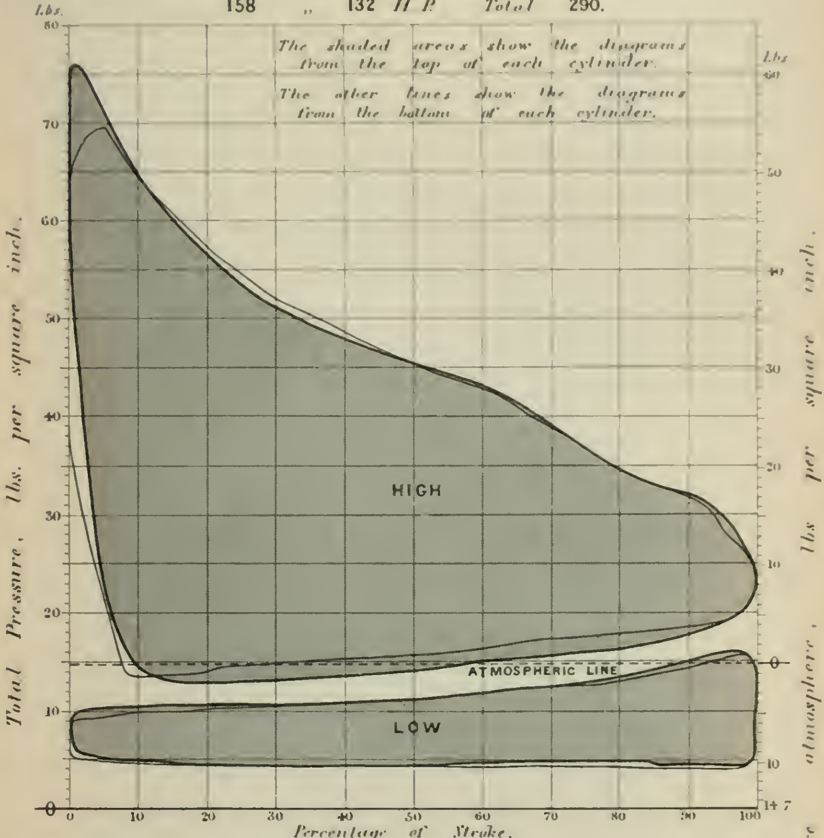


Fig. 2. *Indicator Diagrams from Blowing Cylinder.*
One pair of cylinders, worked by two opposite cranks.

24	*revs. per min.*	$4\frac{1}{2}$	*feet stroke.*
80	*and*	80	*ins. diam. cylinders.*
3·9	,,	3·9	*lbs. mean pressure.*
129	,,	129	*H. P. Total* 258.

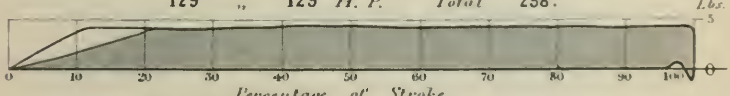
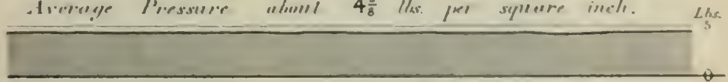


Fig. 3. *Indicator Diagram from Blast Main.*
Average Pressure about $4\frac{3}{8}$ *lbs. per square inch.*

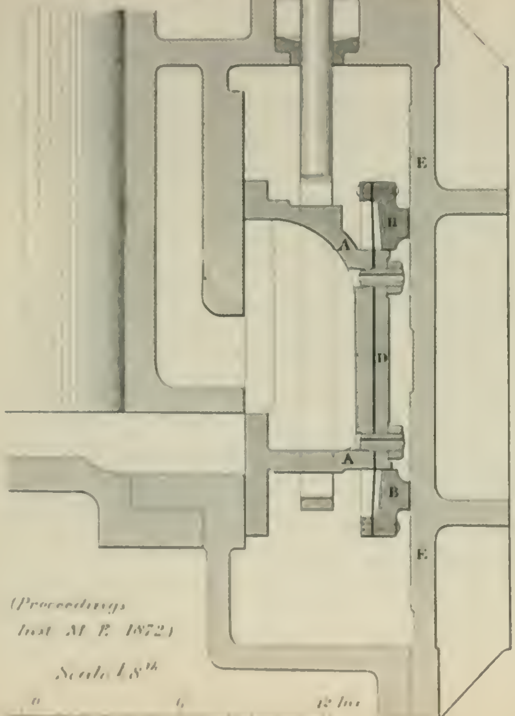


(Proceedings Inst M. E. 1872.)

LACKENBY ENGINES AND BOILERS.

Dawes' Balanced Slide - Valves

Fig. 4. Vertical Section of Valve.



(Proceedings Inst. M. E. 1872)

Scale 1/8th

Fig. 7. Section of Relief Frame at Back of Valve.

Scale 1/4th

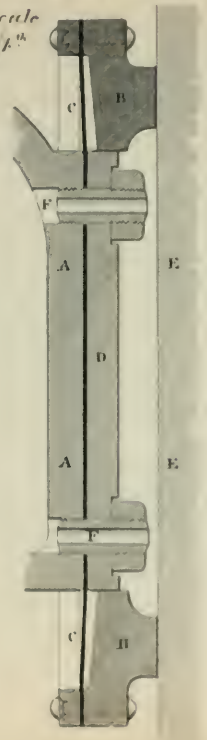


Fig. 5. Back Elevation of Valve

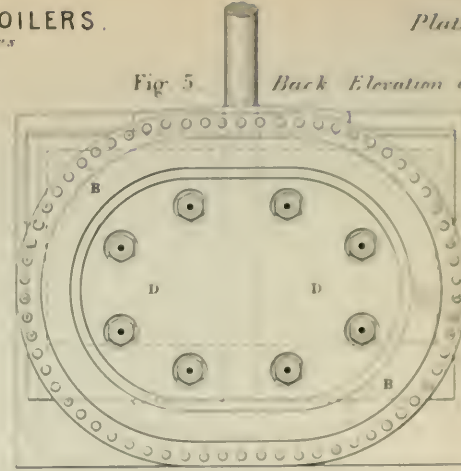


Fig. 6. Transverse Section of Valve.

Scale 1/8th

LACKENBY ENGINES AND BOILERS.

Howard Boiler, at Lackenby Iron Works, Middlesbrough

Fig. 8. *Longitudinal Section.*

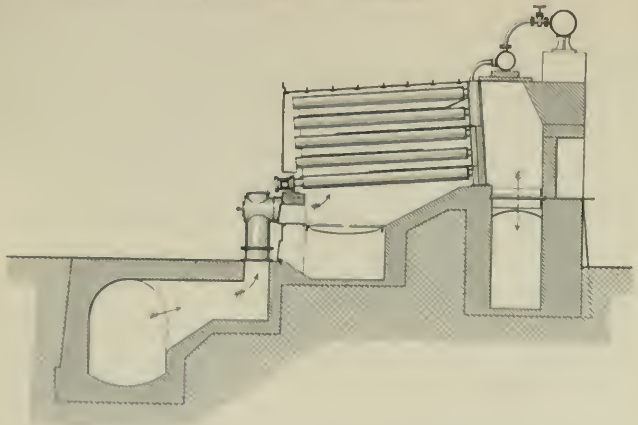


Fig. 9. *Front Elevation.*

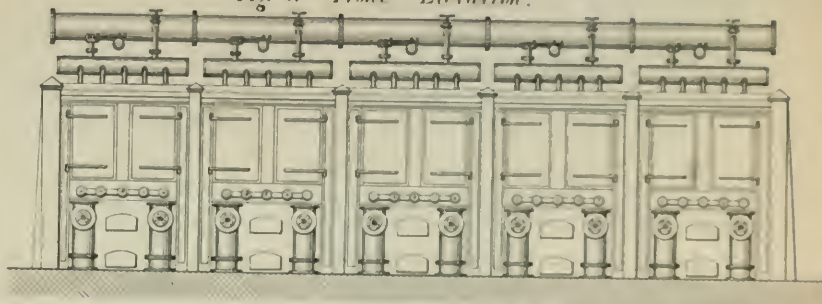
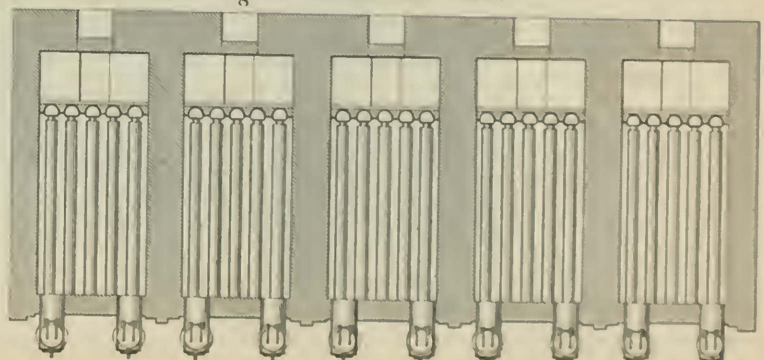


Fig. 10. *Sectional Plan.*



Scale 1/40th

10 5 0 10 20 Feet.

(Proceedings Inst. M. E. 1872.)

LACKENBY ENGINES AND BOILERS.

Plate 75.

Fig. 11. *Longitudinal Section of Howard Boiler.*

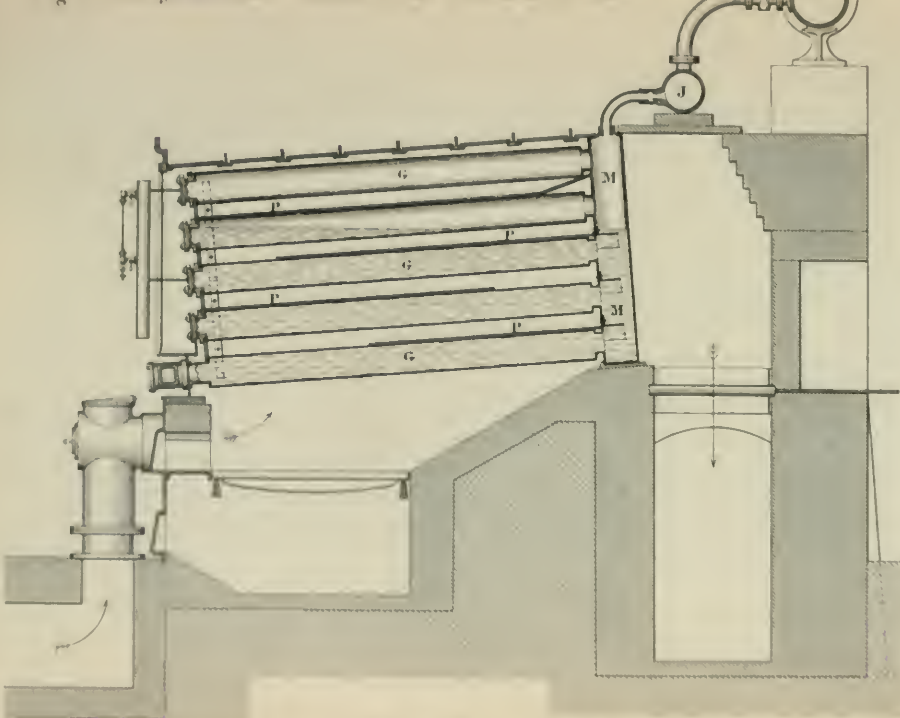
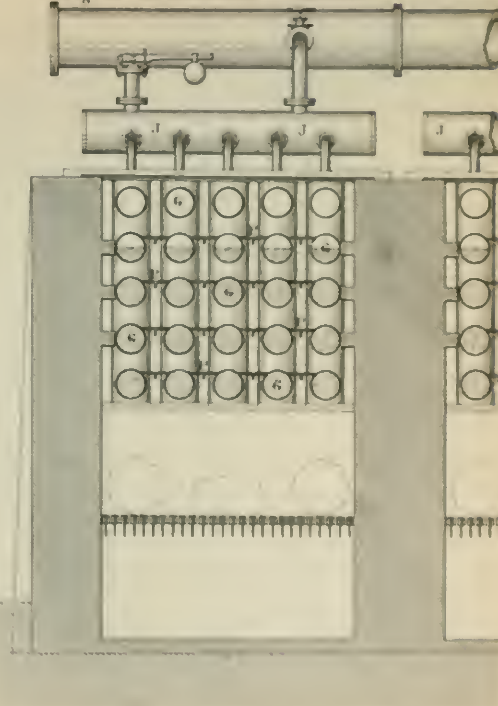


Fig. 12. *Transverse Section.*



(Proceedings Inst. M. E. 1877.)

Scale 1/60th

0 5 10 15 Feet

LACKENBY ENGINES AND BOILERS.

Detail of Tubes in Howard Boiler.

Fig. 13. *Sectional Plan.*

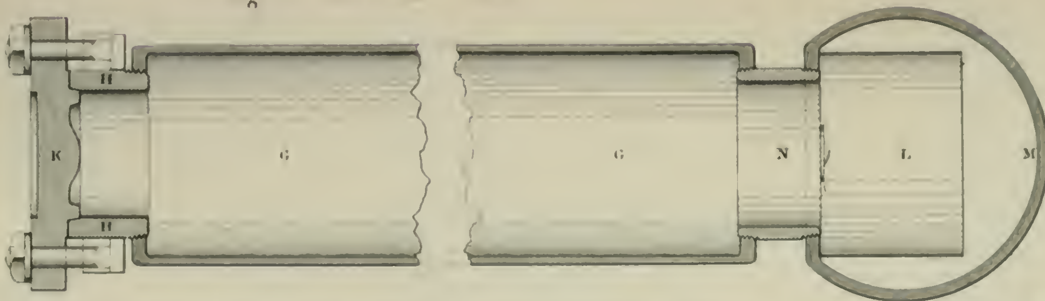
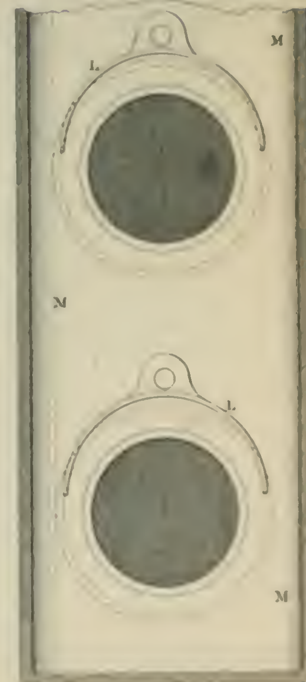


Fig. 15. *Vertical Section of Back Vertical Tube.*



Cast-iron Cap closing front ends of horizontal tubes.

Fig. 16.

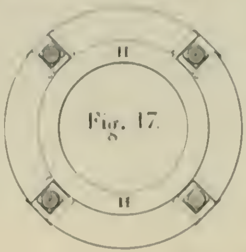
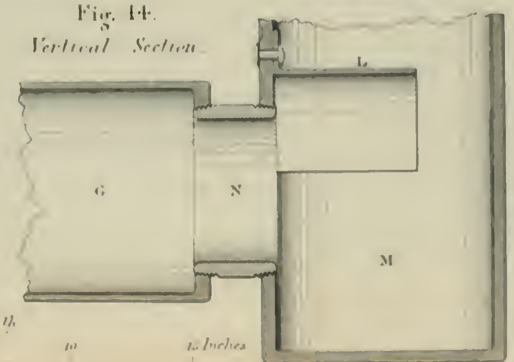


Fig. 17.

Fig. 14. *Vertical Section.*

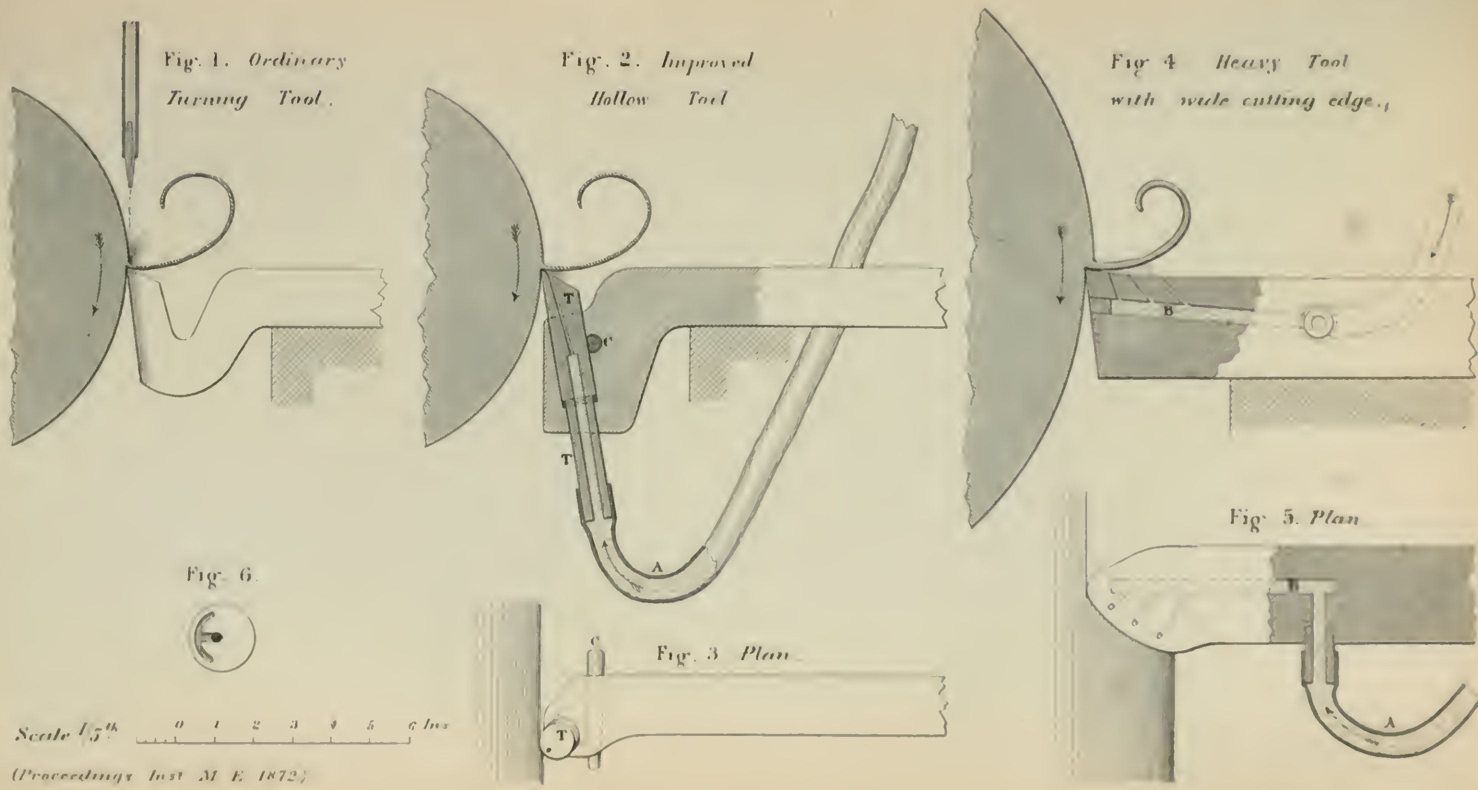


Scale 1/8th

0 5 10 15 *Inches*

HOLLOW TURNING TOOL

Plate 77.



PROCEEDINGS.

31 October, 1872.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 31st October, 1872; C. William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

C. William Siemens, . . . London.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

I. Lowthian Bell, ...	Newcastle-on-Tyne.
Frederick J. Bramwell, . .	London.
William Clay, ...	Birkenhead.
Charles Cochrane, . . .	Dudley.
Thomas Hawksley, ...	London.
Sampson Lloyd, ...	Wednesbury.
Walter May, ...	Birmingham.
William Menelaus, . . .	Merthyr Tydvil.
John Napier, ...	Glasgow.
John Robinson, ...	Manchester.

COUNCIL.

(Five of the number to be elected.)

JOHN ANDERSON, ...	Woolwich.
JOSEPH ARMSTRONG, . . .	Swindon.
EDWARD A. COWPER, ...	London.
T. RUSSELL CRAMPTON, . . .	London.
EDGAR GILKES, ...	Middlesbrough.
THOMAS GREENWOOD, . . .	Leeds.
JOHN KERSHAW, ...	London.
CHARLES P. STEWART, . . .	Manchester.
FRANCIS W. WEBB, ...	Crewe.
RICHARD WILLIAMS, . . .	Wednesbury.

The PRESIDENT announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

THOMAS BULLOCK, JUN., . . .	Birmingham.
THOMAS CHATWIN, ...	Birmingham.
THOMAS JAMES DANSON, . . .	Chester-le-Street.
BENJAMIN ALFRED DOBSON, . .	Bolton.
JAMES J. A. FLOWER, . . .	London.
EBENEZER EDWIN GILBERT, . .	Montreal.
HENRY THOMAS HASSALL, . . .	Birmingham.
JACOB GOWLAND JOICEY, . .	Newcastle-on-Tyne.
WILLIAM KING, ...	Liverpool.
HENRY HYNDMAN LAIRD, . .	Birkenhead.
SAMUEL W. LINSLEY, . . .	Sunderland.
CHARLES MULLINER, . . .	Manchester.
EDWARD JOHN COWLING WELCH, .	Liverpool.
STEPHEN WILSON, ...	Sunderland.
CHARLES WILLIAM WINN, . . .	Birmingham.
WILLIAM LLOYD WISE, . . .	London.

GRADUATE.

ROBERT TWENTYMAN NAPIER, . .	Dumbarton.

The PRESIDENT said that, in pursuance of the preliminary announcement made at the last meeting, he now gave notice that at the Anniversary Meeting of the Institution in January next the two following resolutions would be moved from the chair:—

That notwithstanding anything contained in paragraph 1 of section 5 of the Rules, the next Spring Meeting of the Institution be held in London, instead of in Birmingham; and that the Council be empowered to direct any of the future spring meetings of the Institution to be also held in London.

That the Council be empowered to ask by circular addressed to all the Members, the opinion of each Member as to whether a suitable house should be built for the seat of business of the Institution, and if so in what locality that house should be built.*

The following paper, communicated through Mr. Frederick J. Bramwell, of London, was then read:—

ON THE EJECTOR CONDENSER FOR STEAM ENGINES, DISPENSING WITH AN AIR PUMP.

By Mr. ALEXANDER MORTON, of Glasgow.

The condensers previously used for steam engines, including both injection and surface condensers, require the addition of an air pump, for removing the water continuously from the condenser and discharging it into the atmosphere, and also for removing the air that enters in combination with the steam and injection water; and the air pump in working has to overcome the pressure of the vacuum maintained in the condenser.

The Ejector Condenser entirely dispenses with the air pump, and the exhaust steam escaping from the engine cylinder after each stroke is so directed through a discharge nozzle as to unite in a jet with the injection condensing water, by which it is itself condensed, having first however imparted a sufficient velocity to the combined jet for enabling this to issue direct into the atmosphere in a continuous yet impulsive stream; the contents of the condenser, both water and air, are thus ejected without the use of the ordinary air pump, and at the same time without impairing the vacuum maintained in the condenser. This result is obtained, however low the pressure may be to which the steam is expanded before the exhaust from the cylinder takes place, if the injection water be supplied with a few feet of head pressure; and the effect is produced by taking advantage of the high velocity at which the exhaust steam and the injection water flow into a vacuum, which velocity is altogether wasted in the ordinary condensers, being expended in useless impact of the particles of steam and water within the condenser. The ejector condenser not only discharges

the products of condensation into the atmosphere from a pressure of 12 lbs. per inch below the atmosphere; but with a steam pressure equal to the atmosphere at the commencement of the exhaust, the condenser when applied to a pair of coupled engines is found capable of lifting the condensing water from a lower level of 6 to 8 feet, or raising the discharged water to a proportionate height above the condenser.

The exhaust steam, if discharged from the cylinder at a pressure of 10 lbs. per inch below the atmosphere, rushes into the condenser with a velocity of about 1200 feet per second when a vacuum of 25 inches of mercury is maintained, or $2\frac{1}{2}$ lbs. per inch above a perfect vacuum; and the injection water, which is as much as twenty times the weight of the steam, rushes into the condenser with a velocity of about 43 feet per second. The amount of moving force in the combined jet of water and steam is found to be sufficient to carry all the water, air, and uncondensed steam if any, completely out of the condenser into the hotwell, when the moving force is utilised, as in the ejector condenser, by causing the combined stream to pass through continuously without any interruption to the motion of the jet.

The ejector condenser is shown in Figs. 1 and 2, Plate 66, as applied to an ordinary horizontal engine with 16 inch cylinder; and a vertical section of the simplest form of the condenser is shown in Fig. 3, Plate 67. The injection water enters the condenser in the form of a central jet through the conoidal nozzle A, which is supplied by the branch pipe B; and the area of orifice is regulated by an adjustable central spindle C, which is raised and lowered by an external screw and handwheel. The exhaust steam entering at the branch pipe D passes through the annular space surrounding the central water-jet, and the combined current passes on through the fixed conoidal nozzle F, into the discharge tube G leading to the hotwell; this tube is trumpet-mouthed so as gradually to diminish the velocity of the current as it passes through, and utilise its moving force by avoiding useless velocity at the point of discharge, the enlargement of the tube increasing more rapidly towards its outer extremity.

In starting the condenser, the centre spindle is raised by means of the handwheel, and a jet of injection water is discharged through the centre of the current of exhaust steam from the engine: the injection water being in this case supplied from a level a few feet higher than the condenser, so as to flow into the condenser by gravity. The condensation of the steam by contact with the injection jet produces a vacuum within the condenser, and the water then enters with the velocity due to the difference of pressure between the external atmosphere and the degree of vacuum maintained in the condenser, added to the velocity due to the small head of water in the injection supply. The water jet having a straight passage for its exit without any obstruction retains its initial velocity, and rushes on through the combining nozzle F and the expanding discharge tube G, and issues into the atmosphere in a continuous stream, carrying with it any air mixed with the exhaust steam, the action being somewhat similar to that of the injector for feeding boilers. The vacuum is effected very quickly on starting the condenser, and is complete in only four or five seconds after the time of opening the injection cock.

The moving force in the current of exhaust steam rushing into the condenser from the engine communicates an additional velocity to the water jet on issuing from the water nozzle, the amount of this addition being dependent upon the difference of pressure between the exhaust steam and the condenser; and where the steam is not expanded down in the engine cylinder to a very low pressure before its exhaust, the combined moving force in the water jet is found to be sufficient to effect a continuous discharge into the atmosphere, not only without any aid from a head of water in the injection supply, but leaving a surplus power sufficient for raising the injection water from a lower level of several feet below the condenser. When the injection water is not supplied by a head pressure, but has to be raised from a lower level, the working of the condenser is started in the first instance by means of a small temporary jet of boiler steam, introduced through the central spindle C, Fig. 5, Plate 68, so as to act in the axis of the water jet. The boiler steam

is admitted to this jet through the small piston-valve J, which has a second piston-valve I fixed below on the same spindle. This lower piston is supported by a spiral spring, and communicates with the condenser on the under side by the pipe H; and as soon as a vacuum is formed in the condenser, the piston-valve is drawn down by the pressure of the atmosphere on the top of the upper piston J, causing this piston to shut off the steam jet. In the event of the vacuum ever becoming impaired from any cause, the piston-valve is instantly raised partially by the pressure of the spiral spring below it, and a jet of boiler steam is thus applied by self-acting means to the extent that may be required for restoring the full action of the condenser. The size of condenser shown in Fig. 5 is suitable for a 16 inch cylinder engine, as shown in Figs. 1 and 2.

When the engine makes only a small number of strokes per minute, and the impulses received from the successive discharges of exhaust steam consequently fluctuate materially, a portion of the water fails to get the full velocity of discharge imparted to it, and escapes laterally at the nozzle into the surrounding chamber K, Fig. 5, Plate 68, like the overflow in the ordinary injector. This overflowing water is removed continuously by means of the side return passage L, which communicates with an annular space surrounding the water nozzle A, and the water is carried forward by being brought again into contact with the jet of exhaust steam.

In Fig. 6, Plate 69, is shown the ejector condenser as applied to a pair of engines with 20 inch cylinders coupled at right angles; the only alteration being the addition of a second combining nozzle N fixed beyond the first one, and communicating with a second branch pipe M which brings the exhaust steam from the second engine cylinder. The first nozzle F so completely separates the two steam jets from each other, that the alternate discharge of the exhaust steam from either cylinder cannot in any way impair the vacuum in the other cylinder; the degree of vacuum is found in some cases however to be rather higher in the upper nozzle than in the lower one, the steam in the upper nozzle being the first to come in contact with the injection water. In this condenser

and that shown in Fig. 5, a foot-valve P is provided at the exit orifice of the discharge tube, to prevent any inflow of water from the hotwell when the vacuum ceases at the stopping of the engine.

It is requisite for the injection water to enter the combining nozzle in a straight stream, without any eddy or rotation of the water; and whenever the injection water is supplied with the pressure of a head of 10 feet or upwards, a provision is made for stopping any rotation of the stream, by inserting within the nozzle a guiding piece R with several straight radial vanes, as shown in plan in Fig. 4, Plate 67. In the case of a condenser having a head of 16 feet for the injection water, with several right-angled bends in the supply pipe, the vacuum was found to be liable to frequent disturbance before this guiding piece was inserted, and was sometimes lost suddenly several times in a few seconds; but it has continued constantly steady since the addition of this guiding piece. The proportion that has been found most effective for the injection jet is for the length of the free portion of the jet, which is exposed to the action of the exhaust steam, to be about three times the diameter of the jet, except when the injection water is supplied with a head of 10 feet and upwards, in which case the length of exposed jet is increased with advantage to $3\frac{1}{2}$ diameters.

The ejector condenser has been in use for four years, and there are now about four hundred at work; they have been applied with success to the different classes of stationary engines, from the smallest size up to 50 inches diameter of cylinder. One special advantage of this condenser is that it can be applied with equal success to quick-running short-stroke engines, in which the use of the ordinary condenser is prevented by the difficulty of working an air pump at more than a moderate number of strokes per minute. The action of the ejector condenser is not in any way impaired, however rapid the reciprocation of the engine, but is on the contrary benefitted in that case by the greater uniformity in the supply of exhaust steam.

On account of these condensers having no parts that are in motion, and being very simple in construction, they are found to be very durable, and keep in continued work without requiring any attention or repair. One of the first, which has now been four years in constant work on a horizontal pumping engine at the Ryesholm Pit of the Glengarnock Co., near Dalry, Ayrshire, has not cost anything for maintenance or repairs during the whole time, and has continued working with complete satisfaction. Many others of these condensers have since been successfully applied by the same company to engines that were previously non-condensing, and an important saving in their consumption of fuel has in consequence been effected. The simplicity of construction of these condensers and the absence of moving parts greatly facilitate their application to non-condensing engines, and allow of their being employed where want of space or of convenience for working an air pump would entirely prevent the use of an ordinary condenser.

At the Ryesholm pumping engine a series of experiments have been tried upon the working of the ejector condenser by Professor Rankine, with the following results. Indicator diagrams taken from the engine are shown in Fig. 7, Plate 70, the upper line being taken when working without the condenser, and the shaded diagram with the condenser. The engine has an 18 inch cylinder with $4\frac{1}{2}$ feet stroke, working at 22 revolutions per minute, and developing 24 indicated horse power; the mean effective pressure both with and without the condenser was 16·2 lbs. per square inch, the initial steam pressure being throttled when working with the condenser, to meet the constant resistance of the work. The vacuum in the condenser was maintained almost perfectly steady at 24 inches of mercury; and the consumption of steam per indicated horse power per hour as calculated from the indicator figures showed a saving of 30 per cent. with the condenser, the work done being the same in both cases.

Similar experiments have also been tried by Professor Rankine with an ejector condenser applied to a pair of engines indicating 31 horse power at the Albert Works of Messrs. Neilson at

Glasgow, having $10\frac{1}{4}$ inch cylinders with 18 inches stroke, and running at about 110 revolutions per minute. Indicator diagrams taken from the two cylinders are shown in Fig. 9, Plate 71, the dotted line being from the cylinder exhausting into the upper nozzle of the condenser, and the full line from the other cylinder exhausting into the lower nozzle; their vacuum lines are about $12\frac{1}{2}$ and 12 lbs. respectively below the atmosphere. The mean vacuum in the condenser was $24\frac{1}{2}$ inches of mercury (the barometer being at the time 30·05 inches), and the back pressure in the cylinders ranged between 3 and $4\frac{1}{2}$ lbs. per square inch in the different experiments. The injection water in this condenser was raised from a level of 5 feet below, with steam from 2 to 5 lbs. below the atmosphere at the commencement of the exhaust from the two cylinders; but with a single-cylinder engine of 4 feet stroke, making 60 revolutions per minute, a pressure of steam of about 7 lbs. above the atmosphere at the commencement of the exhaust is found requisite for raising the injection water from the same depth, and with half the speed or 30 revolutions a pressure of about 15 lbs. is required for the same purpose.

In Fig. 8, Plate 70, is shown an indicator diagram taken from a blowing engine indicating 359 horse power at the Llynvi Iron Works, near Bridgend, Glamorgan, which has been working for more than two years with an ejector condenser, having been previously a non-condensing engine. The cylinder is 40 inches diameter and 10 feet stroke, and makes 15 revolutions per minute. It has been in constant work night and day since the condenser was applied, and the apparatus has not required any attention whatever during the time, and maintains a steady vacuum in the condenser of $12\frac{1}{2}$ lbs. below the atmosphere. The injection water is in this case supplied from a head of $1\frac{1}{2}$ feet above the condenser, and the discharged water has a fall of about 9 feet; consequently no starting jet is required, and the construction of the condenser is the same as shown in Fig. 3, Plate 67.

Another indicator diagram is shown in Fig. 10, Plate 71, taken from an engine indicating 15 horse power at the Albert Works, Glasgow, with 8 inch cylinder and 12 inch stroke. With

a steam pressure of about 10 lbs. above the atmosphere at the commencement of the exhaust, it has been found that the discharged water can be raised to the level from which the injection water is received, with as slow a speed of engine as 30 revolutions per minute, or 60 feet per minute speed of piston.

The result obtained from the working of the ejector condenser is that it is quite as efficient as the ordinary condenser and air pump, as regards the degree of vacuum maintained and the amount of back pressure in the engine cylinder; and the whole of the power required to work the ordinary air pump is saved. The quantity of water required by the ejector condenser is the same as that required by the ordinary injection condenser, when the temperature of the water is about that of ordinary river water.

Mr. Morton exhibited a sectional model of the ejector condenser, of a size suitable for an engine with a 9 inch cylinder, and he mentioned that the same size of condenser would do equally well for an 8 inch or 10 inch cylinder; a few inches variation in the size of the cylinder made very little difference in the efficiency of the condenser, as it was only necessary to turn on more condensing water for condensing the greater quantity of steam from the larger cylinders. The range of sizes that had already been made of the condenser was from 6 inches diameter of engine cylinder up to 66 inches diameter. The model showed the arrangement for applying the central jet of boiler steam for starting the condenser to work when the condensing water had to be raised from a lower level; but he considered it was much preferable to have the condensing water supplied with a slight head, because no starting jet of steam was then needed, and the construction of the condenser was thereby much simplified. Where the starting jet of steam had to be employed, it had to be kept on till the

ordinary speed of the engine had been attained, in order that the discharges of exhaust steam into the condenser might be rapid enough to keep up the supply of condensing water.

The PRESIDENT enquired whether the vacuum obtained was pretty steady, or whether any considerable fluctuation was shown by the gauge each time that the exhaust steam was discharged into the condenser.

Mr. MORTON replied that when the exhaust steam was discharged a good deal above atmospheric pressure there was a perceptible fluctuation in the vacuum, which was shown by the vacuum gauge, and amounted in some instances to as much as 3 lbs. diminution of vacuum at the moment of the exhaust. This was not appreciable however in the indicator diagram, the engine being at that moment near the turn of the stroke.

Mr. W. THOMPSON enquired whether the ejector condenser could be applied successfully to marine engines, when it was placed low enough in the ship for the condensing water to be supplied to it always with a head.

Mr. MORTON replied that the condenser answered very well in a steamboat in quiet weather, but in a heavy sea it was useless, because the force of the waves upon the side of the vessel interfered with the regular supply of the jet of condensing water. Only one trial had been made of the condenser at sea, and the violence of the waves caused the jet of condensing water to be intermittent, so that the action of the condenser was altogether unreliable; the condensing water was taken in from the sea first at the bow of the ship and afterwards at the stern, but in both cases the result was unsuccessful, either the movements of the vessel or the force of the waves destroying the steadiness of the water jet, and in future he purposed using a circulating pump.

The PRESIDENT suggested that the difficulty which had been experienced in applying the ejector condenser to marine engines might be overcome by drawing the supply of condensing water not direct from the sea but from a tank within the ship; if the tank were supplied direct from the sea, the force of the waves

would be spent within it, or it might be filled by the bilge pump if necessary. The ejector condenser appeared to him particularly valuable for use in marine engines, and he hoped further endeavours would be made to carry out that application.

Mr. F. J. Bramwell remarked that at the present time surface condensers were in general use for marine engines, for the purpose of obtaining a supply of pure water for the boilers; and he thought therefore there was not much room for the employment of the ejector condenser at sea.

Mr. J. H. Perks said he had a small ejector condenser at work at the Shrubbery Iron Works, Wolverhampton, on a horizontal engine with 14 inch cylinder and 2 ft. 6 ins. stroke, making about 35 revolutions per minute; the boiler pressure was 20 lbs. per square inch, but the pressure in the cylinder was considerably lower. The vacuum maintained in the cylinder was 11 lbs., and that in the condenser in the neighbourhood of the water jet 12 lbs. The condensing water was obtained from the canal, and had to be lifted by the condenser from a lower level of 3 feet; the jet of boiler steam required for this purpose on starting the engine had also to be kept on continuously during the whole time of working, whether much steam or little steam was being used in the engine, as it was found that the vacuum was lost directly if the steam jet was ever stopped. The vacuum gauge showed strong fluctuations at the moment of each discharge of exhaust steam into the condenser. He had not found much economy of fuel from the use of the condenser, as the engine was not working up to its full power, and a considerable quantity of steam was required for maintaining the steam jet in the condenser. The best plan he thought, in all cases where the condensing water had to be raised from a lower level, would be to pump it up in the first instance, so that it should be supplied to the condenser with a slight head of pressure; he had tried supplying the condensing water from a tank fixed about on a level with the top of the condenser, but the experiment had not been satisfactory on account of the tank not being large enough, and not placed quite high enough to admit of dispensing altogether with the steam jet.

Mr. W. Thompson enquired what was the temperature of the condensing water in that case, and what was the maximum temperature of condensing water at which the ejector condenser would work.

Mr. J. H. Perks replied that the condensing water drawn from the canal was at a temperature of about 80° Fahr., which was the usual temperature of the canal water, on account of the large quantity of heated water that was discharged into the canal from many neighbouring works.

Mr. Morton said that in some experiments he had made with Mr. J. R. Napier on the ejector condenser at Messrs. Neilson's works, Glasgow, it had been found that 85° Fahr. was about the highest temperature at which the condensing water could be used, and the temperature of the discharged stream from the condenser was then about 30° higher. With the condensing water therefore supplied at so high a temperature as 80°, the condenser at Wolverhampton was evidently working under disadvantageous circumstances, and the jet of boiler steam would consequently be necessary to keep it going. In general he considered it was preferable to supply the condensing water at a temperature of not more than about 60° Fahr., and in sufficient quantity to prevent its temperature being raised more than about 20° or 25° in the condenser. It was necessary to take care that the condensing water was not greasy, and that there was no grease on the surfaces of the nozzles in the condenser, as the presence of any grease in the orifice of the combining nozzle was found to prevent the combined jet from adhering air-tight to the sides of the expanding discharge tube; the action of the condenser could be altogether spoiled by greasing the nozzles.

Mr. L. Olrick said that he could not reconcile the saving claimed for the ejector condenser in the present paper with the result given by Professor Rankine of his experiments in 1868 with the ejector condenser fitted to the pair of engines at Messrs. Neilson's works; and from the careful and complete manner in which those experiments were carried out, and the eminence of the experimenter, there could be no doubt that they were correct and

reliable. The result was* that the average total quantity of steam condensed, calculated from the increase of temperature in the condensing water, amounted to as much as $2\frac{1}{2}$ times the quantity actually employed in the cylinder, as shown by the indicator diagram, for the purpose of driving the engine and doing useful work. This result showed clearly that a great amount of live steam was taken direct from the boiler by the jet for the purpose of keeping the condenser constantly at work; and as this must necessarily entail a serious expenditure of coal, he should be glad to hear how the more favourable result mentioned in the paper was accounted for.

Mr. MORTON replied that in the case of the Ryesholm pumping engine there was only one boiler, which supplied steam to that engine alone, and the consumption of steam could therefore be measured with great accuracy; the condensing water was also supplied from a higher level, so that no jet of boiler steam was ever required in the condenser in that case. At Messrs. Neilson's works however the same boiler that supplied the shop engines working with the ejector condenser supplied also the steam hammers, and there had been no means of measuring the quantity of steam supplied to the jet in the condenser, which had to be ascertained by calculation; nor had there been the means of measuring with much accuracy the supply of condensing water, from which the quantity of steam had been calculated. The condensing water had in that case to be raised 5 feet by the jet of boiler steam, and in other respects also the condenser had been working under disadvantageous circumstances at the time of the early experiments that had been referred to. As there were two cylinders in that case, there were four discharges of exhaust steam into the condenser in each revolution; had there been only a single cylinder, giving only two discharges per revolution, the jet of condensing water would not have been maintained without a larger jet of boiler steam, the exhaust steam from the cylinder being discharged into the condenser at about 5 lbs. below the atmosphere, as shown by the indicator diagram.

* See Transactions Institution of Engineers in Scotland, 1868-69, pages 76, 78.

Mr. F. J. Bramwell said that one of the ejector condensers had been applied to the portable engine of Messrs. Davey Paxman and Co., which had been working at the recent International Exhibition; and he had made a trial of that engine both with and without the condenser, in the same manner that the engine trials were conducted at the meetings of the Royal Agricultural Society, and with the same dynamometer break that was employed in those trials. No jet of boiler steam was used in the condenser. The condensing water being supplied direct from the waterworks main fluctuated very much in pressure, and a gauge was therefore fixed on the branch supplying the condenser, and a man was stationed at a screw cock to regulate the pressure and keep it as nearly as possible uniform at 3 lbs. per square inch, equivalent to a head of about 7 feet of water. A Siemens water meter was also fixed on this branch, and a vacuum gauge on the condenser. The engine was first tried with the condenser, and afterwards as an ordinary non-condensing engine; each trial was made with a supply of coal equal to 14 lbs. per nominal horse power, and the engine was kept running as long as possible at its regular working speed with this weight of coal. The result was found to be that in working without the condenser the consumption of coal was 5·36 lbs. per break horse power per hour, while with the condenser it was 4·11 lbs., showing a saving of 23 per cent. due to the use of the condenser. The engine made about 110 revolutions per minute, and the vacuum was remarkably steady, a perfectly level vacuum line being maintained in the indicator diagrams. The boiler gave a good evaporation of 9 lbs. of water per lb. of coal; and nearly the whole of the heat in the steam was accounted for in the water ejected from the condenser and in the work done by the engine. The discharge from the condenser flowed horizontally away from the hotwell, and was not delivered at a lower level. The initial pressure of steam in the cylinder, as shown by indicator diagrams taken during the trials, was 50 lbs. above the atmosphere; and the steam being cut off at one eighth of the stroke, the final pressure was considerably below the atmosphere,

and yet as before stated no jet of boiler steam was necessary. The cylinder was not jacketed.

The PRESIDENT enquired what had been the temperatures of the condensing water on entering and leaving the condenser in that trial.

Mr. MORTON replied that the condensing water was supplied at 64° Fahr., and left the condenser at 80°. During part of the trial the quantity of water had been reduced till its temperature on leaving the condenser was as high as 120°; this had been done in order to see how high the temperature of the discharged water could rise without impairing the efficiency of the condenser; with the high temperature of 120° the vacuum fell about 2 lbs.

Mr. L. OLRICK said that the information which had just been given confirmed his views about the ejector condenser, that it would not work constantly unless it was assisted either by a jet of live steam direct from the boiler, or by a head of condensing water, that is, that the condensing water must be drawn from a tank placed at least a dozen feet above the ejector; and if there did not happen to be a natural head of condensing water, pumps would have to be employed, which no doubt amounted to even a greater loss than the steam from the boiler.

Mr. MORTON said the ejector condenser was certainly productive of the greatest economy where there was either a few feet head of pressure for the supply of the condensing water or a few feet fall for the discharged water, either of these plans being equally efficient in maintaining the supply of condensing water without the need of employing a jet of boiler steam for the purpose; the full effect of the condenser vacuum was then gained in the engine cylinder, instead of being impaired by the jet of boiler steam in the condenser. In several cases, such as where the condensing water had to be drawn from a canal at a lower level, a centrifugal pump had been employed to raise the water 8 or 9 feet above the condenser, which was quite sufficient head; the power expended in working the pump was of course so much to be deducted from the economy of the condenser, but was very much less than the power that would be required to work an air-pump. In Wales,

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where many of the ejector condensers had now been applied, there was generally a natural head of condensing water of considerable height.

The President considered that, ingenious as the ejector condenser was, its efficiency might be materially augmented by increasing the extent of surface of the water jet for condensing the steam. The condensing surface was at present limited to the small cylindrical surface exposed to the steam by the short length of central jet intervening between the water nozzle and the receiving nozzle of the discharge pipe. This appeared to him an extremely small surface for absorbing such a large amount of heat as had to be taken up from the steam; and he thought that better results in condensation of the steam, together with some economy of condensing water, would be obtained, if the surface of the water jet could be largely increased, without altering the apparatus in other respects. Such an increase of surface he suggested might be obtained by making the water jet annular, and introducing the exhaust steam by a central jet inside the annular water jet, as well as outside it as at present. The steam would then be condensed both by the internal and the external surface of the annular water jet, instead of only by the external surface of the present solid jet; and judging from the experiments which he had made with an annular steam jet for the propulsion of air, he believed the condensing action of the annular water jet would be much more efficacious and prompt. He enquired whether any trial had been made of an annular water jet.

Mr. Morton replied that he had not tried a large annular water jet in the condenser; and although with the solid central water jet the distance seemed very short and the surface very small for condensing all the steam that came from the engine, he believed the condensing surface exposed by the jet was really sufficient and that the condensation was effected within a very short length of the jet. He had made several experiments bearing upon this point, by inserting a small tube up the centre of the discharged stream from the condenser, with a very small orifice at the top; and when the distance of the top of the tube below the end of

the water nozzle was about equal to the diameter of the nozzle, a central jet of boiler steam being used to maintain the supply of condensing water, the pressure in the centre of the water jet was found to be as much as 100 lbs. per square inch, though the pressure in the central jet of boiler steam was not more than 5 lbs. per square inch at the same time. But on raising the orifice of the tube only about 1-16th inch higher, there was found to be a vacuum in the centre of the water jet. It therefore appeared to him that the steam rushing into the condenser at so high a velocity must be capable of actually penetrating the water jet, and that thus the condensation was effected within the body of the jet as well as at its surface. In the President's experiments on the propulsion of air by a jet of steam it had been found that a large extent of surface of contact was required for the efficient action of the steam jet; but this did not seem to be the case in the ejector condenser, and he had been led to conclude that the steam must have some action of piercing the water jet, because if only the external surface of the water jet acted to condense the steam he thought it would not be sufficient to effect the required amount of condensation.

The President observed that in the experiment which had been described with a small tube inserted up the centre of the discharged jet, it was to be expected that, if the height of the top of the tube were such that it encountered the water of the jet after this had had its motion accelerated by the propelling action of the steam, the great momentum of the water moving at so high a velocity would produce a high pressure by impact upon the orifice of the tube; but if the tube orifice were raised a little higher, it would be clear of the water, and would be exposed only to the central jet of boiler steam, at the point where that steam was itself undergoing condensation by the water jet, and where consequently there would be more or less of a vacuum, as had been mentioned to be the case. He did not think however that there could be any piercing of the water jet by the steam in the condenser, but only an interchange of particles between the colder water in the centre of the jet and the hotter external

portion, which was essentially a gradual process; and the larger the diameter of the solid jet, the greater would be the difference of temperature between the internal and external portions, and the greater would be the loss of condensing water.

Mr. W. Thompson suggested that perhaps a portion of the steam might pass on uncondensed beyond the combining nozzle, and the condensation might continue to go on beyond that point, and even after the combined jet had entered the receiving nozzle of the discharge pipe. In that case the condensing action of the water jet would not be limited to only the short length of jet exposed to the steam between the water nozzle and the combining nozzle.

Mr. J. Robinson thought it was very probably the fact that the condensation of the steam was not confined to the portion of the jet between the two nozzles, but that the condensing action continued to take place further on in the combined jet, as had been suggested. In some extensive experiments made by Mr. Sellers for determining the proper proportions and distance of the nozzles in the boiler injector, remarkable results had been obtained of a somewhat similar character to those mentioned by Mr. Morton, showing the great differences that were produced by only a very small change in the nozzles. He hoped experiments would be made for carrying out the suggestion of an annular water jet in the ejector condenser, with a view to increasing the efficiency of the water in condensing the steam; the application of an annular jet of steam by the President for the propulsion of air had been attended with great success, and had shown the largely increased effect resulting from the increase of surface of contact obtained by the annular arrangement; and similar trials with the ejector condenser would be very useful. In the boiler injector a step in the same direction had been made in Friedmann's injector, in which, instead of all the water being brought at once into contact with the central steam jet, the process was subdivided into two stages, by putting a second water nozzle after the first, so as to supply the water in two successive annular jets; by this means the efficiency of the injector had been considerably increased, and he had no doubt the same

would be the case if the annular arrangement were applied to the ejector condenser, and that the steadiness of the vacuum would thereby be further improved.

Mr. Morton observed that in experiments he had made with a boiler injector having an annular discharge pipe he had not succeeded in making the feed water enter the boiler in an annular jet; and he thought this showed there was likely to be some difficulty attending the annular arrangement for the ejector condenser.

Mr. J. Robinson said it was not meant that the discharged jet from the injector should be annular, but only the initial water jet at the point where it combined with the steam jet; the resulting combined jet would be discharged as a solid jet of water, in which the steam and water had already been thoroughly united together.

The President thought there would not be any difficulty in connection with an annular discharge jet, if the hollow centre of the jet were simply filled up by a fixed solid spindle, the same as he had done in constructing annular jets for the propulsion of air.

The subject introduced in the paper that had been read on the ejector condenser he considered was a highly interesting one, and he moved a vote of thanks to Mr. Morton for the paper, which was passed.

The following paper was then read:—

ON THE WORKING OF THE IMPROVED COMPOUND-CYLINDER BLOWING ENGINES AND HOWARD BOILERS, AT THE LACKENBY IRON WORKS, MIDDLESBROUGH.

By Mr. ALFRED C. HILL, of Middlesbrough.

The Compound-Cylinder Blowing Engines at Lackenby, of which a description was given at the Middlesbrough Meeting last year (see Proceedings Inst. M. E. 1871 page 175), have now been at work for more than a year, supplying blast to two furnaces; they are shown in the engravings accompanying the description, and consist of a high-pressure non-condensing engine, and a low-pressure condensing engine supplied by the exhaust steam from the high-pressure engine. The engines are of the vertical direct-acting kind, and are coupled together with cranks placed directly opposite to each other, with a very light flywheel for carrying the engines over the centres.

The indicator diagrams shown in Figs. 1 to 3, Plate 72, have been taken from the high and low-pressure cylinders, and also from the blowing cylinder and blast main, while the engines were running at their regular speed of 24 revolutions per minute, which is found sufficient to supply blast for the actual make of 800 tons of grey iron per week.

It will be observed that the diagrams from the high-pressure engine in Fig. 1 show that the slide-valves have a little lead; the valves were set so as to leave an opening of the top and bottom steam-ports just perceptible when the engine crank was placed upon the centre. The lap is such that the steam is cut off in the high-pressure cylinder at 63 per cent. of the stroke, expanding through the remainder of the stroke before being exhausted to the low-pressure engine. The initial pressure

upon the piston of the high-pressure engine is considerably less than the boiler pressure of 90 lbs., amounting to only about 60 lbs. in the cylinder; this is on account of the large diameter of the high-pressure cylinder, which is 32 inches, and consequently necessitates the steam being wire-drawn when running at the usual speed of 24 revolutions per minute. The action would no doubt be much better, provided the high-pressure cylinder were smaller, and its proportion to the low-pressure cylinder were made 1 to 4 instead of 1 to $3\frac{1}{2}$; at the same time there is undoubtedly a certain amount of gain from the higher boiler pressure, on account of the steam being of a higher temperature than is due to the initial pressure in the cylinder, and thus preventing loss by condensation in the passages between the two engines and also in the low-pressure cylinder. The steam is admitted direct from the boiler to the steam-jacket of the low-pressure cylinder.

The Balanced Slide-Valves, which are made on Dawes' plan for taking off the pressure by having a moveable back that is connected to the valve by a thin flexible steel plate, have been found to work satisfactorily, and are undoubtedly attended with a saving of wear and tear and of power. The construction of these balanced valves is shown in Figs. 4 to 7, Plate 73. The back of the valve A is surrounded by a relief-frame B, connected to the valve by an elastic steel diaphragm C, which is fixed steam-tight by a cover-plate D screwed on the back of the valve; a margin of 2 inches breadth is left all round for the elastic action, and the circumference of the diaphragm is fixed steam-tight to the outer edge of the relief-frame B by a ring riveted on. The back of the relief-frame is faced, and slides steam-tight against the steam-chest cover E; and the area within the extreme outline of the relief-frame being made nearly equal to the total area of the valve, the back of the valve is relieved from the whole of the steam pressure, excepting only a small portion that is left unbalanced for the purpose of keeping the valve always on its face. The steel diaphragm C,

which is about 1-25th inch thick (0·04 inch), is fixed with a deflection of 1-16th inch when in its place, as shown to a larger scale in Fig. 7, in order to give the required pressure for keeping the back sliding face steam-tight; and its elasticity is sufficient to allow the required lifting of the valve for the escape of any water in the cylinder. To prevent accumulation of pressure upon the back of the diaphragm from any leakage of steam through the back sliding face, a few small holes F, Fig. 7, are made through the back of the valve into the exhaust space.

This construction of balanced valve has the advantage that, as the joint between the valve and the relief-frame is fixed, it remains perfectly steam-tight in working, avoiding the inevitable leakage of a packed joint; and the simplicity of construction and freedom from any loose parts render it very safe and durable, the whole consisting practically of one part only. The valve requires accurate fitting and workmanship originally, but when the two working faces are once got into good condition they continue almost unaffected by subsequent work, on account of the freedom from pressure. These valves have proved thoroughly satisfactory in the Lackenby engines. Similar valves are also used in the colliery locomotives at the Lackenby Works, and have proved quite satisfactory; and they do not involve any objection or inconvenience in their application.

The Surface Condenser of the blowing engines maintains a steady vacuum of 26 inches of mercury, and the actual measured consumption of condensing water supplied inside the tubes is 11 gallons per revolution; in addition to this rather less than $\frac{1}{2}$ gallon of condensing water per revolution is supplied as injection outside the tubes, to make up the required quantity of feed water for the other engines upon the works. The temperature of the water entering the bottom row of tubes is 78° Fahr. in summer, and it leaves the condenser at 115° Fahr.; in winter these temperatures are 58° and 90° with the same consumption of condensing water. The packing of the tube ends, which

are kept tight by means of cotton cord packing in a stuffing-box with screwed gland (as shown in Fig. 7, Plate 48, 1871), has not given the slightest trouble, and continues perfectly tight. The slide-valves and pistons of the steam cylinders are not lubricated with tallow or oil, but with black lead and water; by this expedient the condenser tubes and condenser are kept free from grease. The cost of the water-works water supplied to the boilers is under 1*d.* per ton of iron made, in consequence of the use of the surface condenser. The condensed water from the steam-jacket of the low-pressure cylinder is passed into the hot well, and the average temperature of the feed water is 150° Fahr. at the boilers.

The capacity of each blowing cylinder is 157 cubic feet, consequently the total quantity of blast supplied from both cylinders, at the regular speed of 24 revolutions per minute, is 15,072 cubic feet per minute, measured at atmospheric pressure; thus the supply of blast, including loss by leakage, amounts to 190,000 cubic feet per ton of iron made. The pressure of blast in the blast main, as shown by the indicator diagram, Fig. 3, Plate 72, is very free from fluctuations; this is no doubt partly due to the very large capacity of the blast main, which is $12\frac{1}{4}$ times the joint capacity of the two blowing cylinders. The areas of the inlet openings for admission of air to the blowing cylinders are unusually large, and are ample for the purpose, as shown by the indicator diagrams, Fig. 2, the arrangement of the bottom inlet valves (Figs. 12 and 13, Plate 50, 1871) being the more perfect, as these allow less clearance space than those on the top of the blowing cylinders (Figs. 10 and 11, Plate 50, 1871).

The loss of blast pressure between the engines and the tuyeres amounts to only $\frac{1}{8}$ lb. per square inch; this result is no doubt due to the large area of passages in the cast-iron hot-blast stoves. The average temperature of blast at the tuyeres is above 1200° Fahr., as measured by Siemens' copper-ball pyrometer; and the consumption of coke is less than 20 cwts. per ton of iron made from all Cleveland mine. The indicated horse power of the engines is found from the diagrams to be 158 for the high-pressure engine,

and 132 for the low-pressure; giving the total of 290 indicated horse power for the pair of engines. The indicated power of the two blowing cylinders together is similarly found to be 258 horse power, or 89 per cent. of the power of the engines.

The engines run with remarkable smoothness and regularity, and a halt upon the centres is only perceptible when they are running as slowly as 13 revolutions per minute against a blast pressure of $4\frac{1}{2}$ lbs. per square inch. The wear and tear upon the brasses of the connecting rods and of the carriages of the flywheel shaft is at the same time very small, clearly showing that the friction upon the bearings is very little. The indicator diagrams from the high and low-pressure cylinders, taken in connection with the relative areas of the pistons, show that the total effective pressures at any moment of time upon the two pistons are pretty nearly equal, thus preventing any sudden acceleration or racing of one engine over the other; and consequently there is very little torsional strain upon the flywheel shaft. The engines run continuously for three weeks at a time without stopping.

The Howard Boilers employed at the Lackenby Iron Works are shown in Figs. 8 to 10, Plate 74, and also to a larger scale in the longitudinal and transverse sections, Figs. 11 and 12, Plate 75. They consist of a series of nearly horizontal wrought-iron tubes G G, of 9 inches outside diameter, arranged in vertical rows, the tubes in each row being closed at the front end, and connected at the back end by a vertical main M of D section, as shown to a larger scale in the sections, Figs. 13 to 15, Plate 76. The joint is made by a short coupling-piece or nipple N, of 7 inches outside diameter, screwed with a slight taper into the flat side of the D shaped main M; and upon the other end of the nipple the horizontal tube is screwed, also with a slight taper. The front end of each tube is closed, as shown in Figs. 13, 16, and 17, with a flat welded end, into which is screwed with a slight taper a cast-iron head H; upon this a cap K is fitted with a carefully turned conical joint, and secured by four bolts; these joints are all found to be quite tight in working. There are five

tubes in each vertical row in the boiler, set with a downward inclination of 1 in 12 towards the front end, as shown in Fig. 11; the water level stands usually about at the height of the top tube but one, and the top tube in each row forms the steam space, from which the steam passes off into the external steam receiver J. No internal circulating tubes are employed, but a short piece of arched plate L is fixed inside the vertical D main over the aperture of each horizontal tube, as shown in Figs. 13 to 15, for the purpose of facilitating the separation of the water entering the tubes, and the steam escaping from them. Each boiler contains 25 horizontal tubes, arranged in five vertical rows, and the feed water is introduced at the front or lowest end of each of the bottom tubes. The boilers are heated entirely by the waste gas from the blast furnaces; and the heat is made to traverse backwards and forwards on its way to the chimney, by means of deflecting plates PP, Figs. 11 and 12, laid between the lower rows of tubes.

The part that was considered most likely to fail in these boilers, namely the screwed joints at the back end, by which the horizontal tubes are attached to the vertical D main, have never given the least trouble; they have always been tight and still continue so. The cleaning of the boilers internally is an easy process by taking off the front caps of the tubes, and as a rule they are cleaned once a month, the thickness of scale after that length of working never exceeding ⅛ inch. The outsides of the tubes are cleaned of gas-dust every fortnight, and the heat is absorbed satisfactorily, the temperature of the escaping gases averaging not more than 560° Fahr.

There are five of these boilers of 50 horse power each at the Lackenby Works, and they supply all the steam required for the blowing engines, and also for two pumps with steam cylinders of 12 inches diameter and 24 inches stroke, which are situated at a distance of 200 yards from the boilers; these pumps supply the water to the tuyeres of the two blast furnaces, and to the circulating pump of the surface condenser of the blowing engines, the total quantity of which is found by actual

measurement to be 486 gallons per minute raised to a height of 78 feet. The boilers also furnish steam to a steam-ram lift for the calcining kilns and bunkers; the ram is 36 inches diameter with 48 feet stroke, and lifts one truck at a time at the rate of 114 feet per minute, and works only during the day. The total weight of materials lifted by it per day to the height of 48 feet, including the trucks and the preponderance of the ram itself, is 952 tons, consisting of

Ironstone	372	tons.
Limestone	68	„
Coke	114	„
Coals	20	„
Trucks	317	„
Preponderance of Ram	61	„
Total	952	tons.

The boilers also supply steam to the furnace lift, which is worked by an engine with 15 × 24 inch cylinder, geared 10 to 1, and lifts 468 tons of materials 92 feet high every 24 hours, consisting of

Calcined ironstone	286	tons.
Limestone	68	„
Coke	114	„
Total	468	tons.

The boilers do the whole of the above work easily without the use of coals for firing them, the use of coals being only necessary when the furnaces are deranged through want of materials, or when one of them stands longer than usual at casting time. Although the steam ram necessarily takes a large quantity of steam suddenly, the boilers prime very little. Three boilers out of the five would be sufficient to raise the steam required for the blowing engines alone.

Upon the whole, and under the conditions in which these boilers are working, they do quite as much work, if not more, than the usual number of cylindrical boilers employed for two blast furnaces in the Middlesbrough district; and where the quality of water is good, they are considered by the writer to be highly

satisfactory. This has been found to be so far the case with the present boilers at Lackenby that three more of the same construction are about to be put down for supplying steam to the additional furnace plant now being erected at those works.

Mr. Hill mentioned that the indicator diagrams exhibited from the blowing engines had been taken after they had been running regularly for nine months; he had taken better diagrams from them on several different occasions, but he considered those exhibited gave a fair average representation of the ordinary working of the engines. Both engines and boilers still continued working well at the present time, and he was thoroughly satisfied with the efficiency of their performance.

Mr. D. Halpin asked whether any experiments had been made with the balanced slide-valves of the blowing engines, to ascertain their friction and the power required to work them.

Mr. Hill said he had not tried any experiments upon that point, but the great reduction of the friction with the balanced valves was shown by the fact that the valve spindles were not more than $1\frac{3}{8}$ inch diameter, with a cylinder of 32 inches diameter and a boiler pressure of 90 lbs., and such slender spindles would certainly not stand the work if the valves were not balanced; in marine engines of that size, with a lower boiler pressure, the valve spindles were considerably more than double the strength.

The President enquired whether there had been any trouble in getting the balanced slide-valves into good adjustment as regarded the front and back rubbing surfaces, and whether there had been any difficulty in keeping them in good condition during working.

Mr. Hill replied that there had been no difficulty in getting the valves correctly to work at starting, and the front and back rubbing faces having once been carefully adjusted, they had continued

working well ever since without any alteration. They had never been taken out, but had only been moved up and down to examine the port faces when the back cover of the steam chest was taken off; the faces of the valves and ports were all found to be wearing well, and the inside surface of the back cover had become quite polished. Balanced slide-valves on the same construction were also in use in the colliery locomotives at the Lackenby Works, with 130 lbs. steam pressure; and though the engines primed occasionally, this did not seem to affect the working of the valves in the slightest, as they continued in good order, and were quite steam-tight. Not having been previously acquainted with these valves, he had been advised by the makers of the engines, Messrs. Kitson, to try them for these blowing engines, and had been quite satisfied with the very successful results of their working.

Mr. A. Paget observed that there were some small holes made through the back of the valve for preventing accumulation of pressure on the valve through any accidental leakage, and he wished to know whether there might not possibly be a danger that if the back of the valve began to leak a considerable leakage might take place without being detected, the steam blowing right through into the condenser; and he enquired whether any plan had been tried to obviate this danger.

Mr. Hill replied that he had tested this by plugging up the holes in the back of both the valves of the high-pressure engine, and fixing a cock upon the centre of the steam-chest covers; there was not found to be any perceptible leakage of steam when the cocks were opened, showing that the valves were practically steam-tight. The plugs and cocks had not been removed from those valves, but the valves of the low-pressure engine continued working with the holes open.

Mr. H. P. Holt said he had fitted a number of these balanced slide-valves for stationary, marine, and locomotive engines, and had never had any trouble with them. By increasing the area included within the relief ring at the back of the valve, it was possible to relieve the valve of the pressure on its back to any degree that might be necessary; in some of the earlier instances the extent of

relief had been overdone, so that the valve had been entirely lifted off the face by the compression of the exhaust steam within the cylinder at the end of the stroke. This construction of valve was now being applied to locomotives with inside cylinders by fixing a dead plate between the backs of the valves, for the relief rings to work against, the width of valve-chest required between the two cylinder faces for the balanced valves being no more than for ordinary valves.

The PRESIDENT enquired how many boilers had now been made on the principle of those in use at the Lackenby Works.

Mr. E. T. BOUSFIELD, from the works of Messrs. Howard, Bedford, said they had now made about 550 of these boilers; about half the number had been made with the tubes arranged vertically, instead of horizontally as at Lackenby, the latter being the arrangement now generally preferred, as it afforded special facility for inspecting and cleaning the tubes internally and externally, every part being exposed to full view from the front upon the soot doors being opened; the number of separate parts was also reduced to a minimum.

Mr. R. H. TWEDDELL asked how the screwed joint at the back end of a tube was undone, for the purpose of putting in a new tube; and whether a single tube could be removed or replaced without disturbing the rest. He had understood a great advantage in that construction of boiler was the ease with which it could be repaired; but after it had been worked for a length of time he thought there would be some difficulty in unscrewing the joints, more especially when the boiler was used for sea-going purposes.

Mr. E. T. BOUSFIELD replied that any tube in the boiler could be readily removed and replaced without interfering with any of the others. The screwed joints certainly required a considerable amount of force to unscrew them, but with proper appliances no difficulty was found in unscrewing them. The front cap was taken off the tube to be removed, and a wrench or spanner fitting the bolt lugs on the cast-iron head was then applied, with a handle long enough for a sufficient number of men to act upon it; or tackle was employed for obtaining the

required power. A heated iron collar was slipped over the tube and pushed back to the end, to expand the tube end sufficiently for easing the screwed joint. There was no risk of the tube itself breaking in unscrewing the joint, the strength of the tube being much greater than that of the joint; nor would the front joint yield instead of the back one, as the tube at the front end was screwed into the cast-iron head, and a screwed joint made between wrought iron and cast iron did not yield so soon as one of wrought iron and wrought iron. He showed specimens of the horizontal tube, the screwed nipple, and the vertical D shaped tube at the back end of the boiler, and of the cast-iron head and cap closing the front end of the horizontal tubes.

Mr. W. Thompson asked whether any of these boilers were working at sea.

Mr. E. T. Bousfield said at the present time there were not any of the boilers at sea; some had been at work for a short time at sea, and considerable experience had been gained, but owing to circumstances not connected with the boilers the matter was being delayed.

The President enquired how far the successful working of the boilers was dependent upon the quality of water employed.

Mr. E. T. Bousfield replied that, among the number of these boilers already at work, there had now been experience of their working with all kinds of water; and of course, as with other boilers, the purer the water the better. These boilers however afforded great facilities for cleaning out by taking off the front caps of the tubes, and in most cases they could be cleaned more readily than other descriptions of boilers, thus giving them an advantage when having to work with water that contained much deposit. All ordinary hard scale was very easy to clean out, as it came off the surface of the tubes in thin flakes, in consequence of the contraction of the tubes in cooling; in some few cases where the deposit was slightly elastic it was more difficult to remove.

The President asked how the vertical tubes at the back of the boilers were cleaned out.

Mr. E. T. Bousfield replied that it had not been found necessary to provide special means for cleaning out the back vertical tubes, as there was very little evaporation in them and consequently very little incrustation. If requisite, they could be cleaned by disconnecting the steam pipe at top and unscrewing the cover, which would give ready access.

Mr. Hill said that the entire cleaning of any one of the boilers at Lackenby, containing 25 horizontal tubes, was done by one man and a boy within twelve hours; the water was let off at six o'clock at night, the front caps all taken off, the tubes cleaned out, the caps refixed, and the boiler was got to work again by six o'clock next morning.

The President remarked that it was a general opinion among ironmasters that blowing engines could not be worked expansively to any great extent, because the work the engine had to do was certainly unfavourable for the expansive action of the steam, the pressure of the steam being greatest at the beginning of the stroke and diminishing towards the end, while the blast pressure rose from nothing at the beginning of the stroke and continued to exert its full resistance to the end. It would be interesting therefore to know whether any inconvenience had arisen from the unusual extent to which expansion was carried in the Lackenby blowing engines.

Mr. Hill said he had never experienced any inconvenience from the degree of expansion at which the engines were working. If there were any considerable strain between the two engines the bolts and keeps of the flywheel-shaft carriages would certainly fail, as they were small in proportion; but they had stood well, and the engines worked very steadily.

The President enquired what was the size and weight of the flywheel, and whether any degree of irregularity was perceptible in its revolution.

Mr. Hill replied that the flywheel was 16 feet diameter and weighed only about 12 tons, which was not more than about half the weight generally used with ordinary beam engines. There was no perceptible irregularity in the motion of the flywheel

when the engines were running at their usual speed of 24 revolutions per minute; it was only when the speed was as low as 13 revolutions per minute that a slight halt on one centre could just be observed.

Mr. T. Claridge thought the arrangement of compound-cylinder expansive blowing engines with surface condenser might be advantageous, where coal had to be used for raising the steam to drive them, and it was consequently of importance for the utmost economy of fuel to be effected; but where the steam was raised entirely by combustion of the waste gas from the blast furnaces, as at Lackenby, there was no occasion for any further economy of fuel, and in such cases therefore he did not see the desirability of adopting what appeared to him a complicated arrangement of engine. As simple an arrangement as possible seemed to him the most suitable for blowing engines for blast furnaces, in order that there might be the least possible liability to stoppages; and he considered the engine that could be kept going the longest was the best for blast-furnace purposes. It appeared to him that there was a good deal of complication in the arrangement of blowing engines now described, and he thought the test of several years' working would be needed to establish the success of the plan.

Mr. F. J. Bramwell did not think that any complication was involved in the arrangement of the blowing engines described in the paper. He believed it would be generally admitted that the kind of engine most likely to work with regularity was one in which the two cylinders worked together upon the same crank shaft; and he could not see how any complication was introduced by simply working one cylinder with high-pressure steam, and the other as a low-pressure cylinder supplied with steam from the exhaust of the high-pressure cylinder. As regarded surface condensers, now in general use for marine engines, where least of all could any risk of stoppage or of derangement be permitted, they had been proved by long and extensive experience to be thoroughly satisfactory. With a surface condenser the danger of variation in the supply of the water for injection was avoided, and a steady vacuum was

thus maintained, while at the same time pure feed water was procured for the boilers, preventing the formation of deposit, and thereby removing one great element of destruction. For the purpose of keeping blowing engines at work therefore with great regularity and for a long continuance, he thought the arrangements described in the paper were particularly suitable.

Mr. Hill concurred in considering that the arrangement of the Lackenby blowing engines presented no complication; in several respects they were different from the blowing engines in general use in other iron-making districts, and the points of difference had proved decidedly advantageous in working. The two blast furnaces at Lackenby were together making 800 tons of iron per week with a consumption of less than 20 cwts. of coke per ton of iron made; that was the whole consumption of fuel, no coal whatever being burnt under the boilers unless under exceptional circumstances, and he thought such an extent of economy would be accepted as a satisfactory proof of the success of the blowing engines and boilers.

Mr. Chapman observed that, in consequence of the use of the surface condenser, the cost of the water supplied to the boilers had been stated to be under 1*d.* per ton of iron made; and he enquired what would have been the cost if the surface condenser had not been employed.

Mr. Hill replied that, had the surface condenser not been used, the water supply for the boilers would have cost 4*d.* per ton of iron made, as it was water-works water that had to be used at the Lackenby Works; and the surface condenser thus effected a saving of 3*d.* per ton of iron made.

The President moved a vote of thanks to Mr. Hill for his paper, which was passed.

The following paper was then read:—

ON AN IMPROVED CONSTRUCTION OF TOOL FOR TURNING METALS AT INCREASED SPEED.

By Colonel CLAY, of Liverpool.

Many improvements have been made from time to time in the Tools and appliances for turning and shaping metals; the tools have been duplicated and multiplied in special cases, and improved forms have been introduced with more or less success; but as far as the writer is aware no attempts have been made to increase the efficiency of the individual tool by increasing its speed of working. His attention was drawn to the subject by a question being raised as to the reason why the speed is limited to the very slow rate in universal use, and whether the operation of turning and shaping metals could not be considerably accelerated beyond a surface speed of about 10 to 15 feet per minute, which is the practical limit in this class of work. The objection to an increase of speed is that the cutting tool would become heated, and would consequently lose its temper and utility; for it is kept cool by water dropping upon the work from a can and delivery tube placed just over the tool, and an increase in the quantity of water supplied would fail to cool it sufficiently at a higher speed of working, because very little if any of the water actually comes in contact with the cutting edge, the water being guarded from it by the shaving of metal, upon the upper surface of which it is delivered, as illustrated in Fig. 1, Plate 77.

It occurred to the writer that if the water could be supplied direct to the cutting edge itself, and in sufficient quantity to carry off all the heat liberated by the operation of turning, the speed of the operation might at once be increased very considerably, without any difference in the condition of the tool from that existing with the ordinary slow speed. This object he

succeeded in effecting by means of the tool shown in Figs. 2 and 3, Plate 77. A hole is drilled throughout the length of the cutting portion of the tool T, to the bottom end of which is connected the india-rubber tube A from the ordinary water can. The upper end of the hole terminates near the cutting point of the tool, and a constant jet of water is delivered from it, and is discharged on the underside of the shaving that is being cut off, and plays upon the point of the tool so effectually as to keep it thoroughly cool when the speed of surface is increased many times beyond the ordinary limit.

In Figs. 4 and 5 is shown a modification of the plan for application to a heavy turning tool having a wide cutting edge. In this case a hole B is drilled into the tool longitudinally near the upper surface, and a transverse hole drilled into it at the inner end, which has a short nipple screwed in for the purpose of attaching the india-rubber feed tube A from the water can. The front end of the longitudinal hole is stopped by a wood plug, and three small oblique holes are drilled down into it from the upper face of the tool, terminating near the cutting edge; by this means a constant supply of water is maintained, flowing over the whole of the cutting edge to keep it cool.

The upper portion of the holes in each of the tools is drilled very small, about $\frac{1}{8}$ inch diameter, to prevent weakening the tool; but the body of the hole can be made any size that is convenient. No inconvenience in working is involved, as the ordinary water can is used, and the india-rubber tube has simply to be slipped upon the nipple or the tool end. It is not necessary for the tool to be drilled at all for the purpose, as the water can be applied as effectually by an external jet, provided that the jet plays upon the same place, between the point or edge of the cutter and the under surface of the shaving that is being cut off; the drilled hole in the tool is adopted as a convenient mode of applying the jet.

The speed at which wrought iron can be turned is generally considered to be limited to from 15 to 20 feet per minute, but in practice this speed is seldom obtained, the actual speed

of work being from 10 to 15 or an average of about 13 feet per minute. With the hollow tool the speed has been increased to 60 feet per minute, or four times the ordinary speed, with heavy cuts in a 12 inch lathe; and with light cuts has been further increased to 110 feet per minute, or eight times the ordinary speed, the tool keeping quite cool and working well at that high speed. When it is considered that the time required for getting through a piece of work in the lathe is determined directly by the speed, the practical value of any increase in the ordinary speed will be seen to be very considerable, both in saving time with a job, and in getting so much more work out of each lathe in the same time.

Colonel Clay exhibited specimens of the turning tools described in the paper, and remarked that it was not material whether the water was supplied through a hole in the tool itself, as in the specimens exhibited, or by a separate external jet; the only object was that a sufficient supply of water should be delivered on the cutting edge itself of the tool, to keep it cool in working. Trials had been made of the hollow tool at some of the principal engineering works in London, the speed of the lathes being increased by throwing out the back gear and driving with single gear; but the driving belts slipped before the limit of speed that the tool would stand had been reached. The tool tried was one of the ordinary round tools of Messrs. Smith and Coventry's make, of the size usually employed for a 12 inch lathe. The larger tool shown in the drawings, with the wide cutting edge, had been tried at the Birkenhead Iron Works, turning off a shaving 1-16th inch thick from a shaft 8 inches diameter at a surface speed of 95 feet per minute; and a screw shaft 11 inches diameter and 20 feet long had also

been turned by the tool at the speed of 27 feet per minute. From 15 to 20 feet was the speed usually spoken of with the ordinary tools, but in practice he had generally found the speed actually attained in regular work did not exceed from 10 to 14 feet per minute, according to the rate of traverse employed. The plan of making the round cutter bear with a small shoulder in the toolholder, as shown in Fig. 2, Plate 77, for enabling it to take very heavy cuts without slipping, was an improvement intended to meet the objection frequently felt to attempting a heavy cut, on the ground that the set-screws ordinarily employed for fixing the cutter in the holder were not sufficient to prevent it from slipping under a heavy cut. When the cutter had been ground down it could be set up again to the proper height by simply inserting a washer of the required thickness in the socket in the toolholder, underneath the shoulder of the cutter. For securing the cutter in the toolholder he employed a small taper steel pin with a flat side (C, Figs. 2 and 3), driven in transversely so as to jam the cutter in its socket; this he considered would be found much more convenient than the ordinary set-screws, particularly in shops where these tools with separate cutter and holder were not in regular use, because it frequently happened that the special box-spanner required for the set-screws got mislaid, and some time was lost in looking for it when it was wanted; but with the taper pin anything would do for knocking it out or tightening it up, so that there would never be the slightest difficulty or delay in removing or fixing the cutter. The object of the improved tool was to give increased facilities for turning and shaping metals in a quicker manner than had hitherto been practicable; and whatever increase in speed of work might be obtained with the new tools, he was satisfied that some benefit would result from showing that even with existing tools more work could be done than had usually been obtained.

Mr. W. Ford Smith said he had made a few experiments with the new hollow cutter, but not for a sufficient length of time to determine the quantity of work done by it as compared with that

done by the ordinary cutter in the same time. With an ordinary solid cutter he had turned small shafts of $1\frac{1}{2}$ inch diameter at a cutting speed of 30 feet per minute, making 20 revolutions to each 1 inch of traverse; and with the hollow cutter cooled by the water the speed had been increased to 47 feet per minute; the cutter in that instance was inverted in the lathe, so as to cut downwards instead of upwards. The quantity of work done in a given length of time however, though rather more than that got through with the ordinary cutter, was not in that instance proportionate to the increase of speed, because a good deal of time was lost at starting, in consequence of its being impracticable to start the lathe at once at the high speed; it had accordingly been necessary to start at first with the slower speed, and afterwards to throw on the high speed. Further experience was therefore desirable in regard to the relative quantity of work done. He had not himself met with any difficulty from the cutter getting pushed down in the toolholder in taking a heavy cut, when held only by set-screws; in turning a Bessemer steel shaft of 7 inches diameter with $\frac{1}{2}$ inch depth of cut and $\frac{3}{8}$ inch traverse per revolution, he had not found the cutter slip, though secured only by the set-screws which were not tightened up more severely than usual; the cutter in this case was held by two steel set-screws with hardened ringed ends.

The President observed that the superiority of the hollow tool seemed to be attributed simply to the cooling effect of the water upon the cutting edge of the tool; and he suggested that part of the advantage might be attributable to the cutting edge being also lubricated by the water jet. This could not take place in the ordinary arrangement, where the water was thrown off by the shaving and did not get to the cutting edge of the tool; but with the hollow tool the water jet would not only cool the cutting edge but also lubricate it.

Colonel Clay said the object he had had in view had been simply to bring the cooling action of the water as near as possible to the cutting edge of the tool; and for the purpose of more effectually accomplishing this object one plan tried had been

to cut a shallow groove in the upper face of the tool, immediately behind the cutting edge and parallel to it, and communicating by a channel with the water hole in the tool, Fig. 6, Plate 77, so as to make sure of the water getting as close up to the cutting edge as possible, and to avoid the risk of its being prevented from doing so by the shaving ever getting in the way. The trials at present made with the hollow tool had all been made with plain water, not soap and water; but the lubrication of the cutting edge was no doubt an important matter, and it would be well for further experiments to be tried in reference to the suggestion now made upon that point. Another matter which had not yet been sufficiently attended to in the trials of the new tools was the proper angle of the cutting edge, and he did not know whether the angle had been made to agree exactly with that which was found the best in the ordinary tools. There could be no question however as to the very important increase of speed, which caused the shavings of metal to fly off in a small lathe just like shavings of wood; in some of the trials he had made, the speed had been as much as 110 feet per minute in taking a finishing cut.

The PRESIDENT considered the improved tool was a very simple and efficient contrivance, and likely to meet with very general adoption. He proposed a vote of thanks to Colonel Clay for his paper, which was passed.

The Meeting then terminated.

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